JPRS L/9938

25 August 1981

USSR Report

LIFE SCIENCES

BIOMEDICAL AND BEHAVIORAL SCIENCES

(FOUO 10/81)

FBIS FOREIGN BROADCAST INFORMATION SERVICE

FOR OFFICIAL USE ONLY

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400040050-8

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400040050-8

JPRS L/9938

25 August 1981

USSR REPORT
LIFE SCIENCES
BIOMEDICAL AND BEHAVIORAL SCIENCES

(FOUO 10/81)

CONTENTS

BIOCHEMISTRY

UDC: 578.087.1

ALGORITHMS IN BIOMETRICS

Moscow ALGORITMY BIOMETRII in Russian 1980 (signed to press 19 Nov 80) pp 2-4, 11-13, 87-88

[Annotation, foreword by Prof B. V. Gnedenko of Moscow State University, academician of the Ukrainian Academy of Sciences, introduction and table of contents from book "Algorithms in Biometrics", by Nikolay Aleksandrovich Plokhinskiy, 2d edition, revised and enlarged, edited by Prof B. V. Gnedenko, Moscow Society of Naturalists, Izdatel'stvo Moskovskogo universiteta, 4900 copies, 150 pages, illustrated]

[Text] The second edition contains 60 algorithms (there were 29 in the first) and explains how they are used. The algorithms are referable to five areas of modern statistical biology [biometrics]: summary characteristics of tags, theory of representativeness, variance analysis, mathematical models in biology, informative indicators in biology. The second edition of algorithms is intended for specialists in biology, university students and instructors, as well as industrial workers in the field of agriculture.

Foreword

Problems related to the content and nature of mathematical education of biologists have never been as important as today. The exceptional complexity of biological phenomena, on the one hand, and comprehensive penetration of physicochemical and technical methods of research, on the other, as well as the turn to investigation of microbiological and global processes, inevitably lead to the necessity of studying mathematical methods in biology. We must have broader ideas about the capabilities of modern mathematics, and there must be joint participation, on a regular basis, of biologists and mathematicians in solving major and pressing biological problems.

How can a mathematician know what he must give primarily to a biologist with respect to mathematical information if he does not have even a superficial idea about the tasks of biological science? How can a biologist demand an explanation about some parts of mathematics or other of mathematicians, if he has no conception of its capabilities?

The mathematical education of biologists should be based on profoundly comprehended and interpreted needs of biological science. Courses of mathematics at biology faculties should be planned on expressly this basis. This also would implement entirely the remarkable thesis of V. I. Lenin, to the effect that human cognition is proceeding from vivid contemplation to abstract thought, and from the latter to practice.

We must admit that the first and final phases of this scheme for acquiring knowledge have disappeared from mathematics courses for biologists, and only the bare middle part remains. As a result, a biologist does not see the link between mathematical concepts and the problems, to the solution of which his life is dedicated.

The existing literature on mathematics for biologists is extremely spare in our country, while the need for it is enormous. Unfortunately, the existing textbooks are very abstract or mediocre.

In my opinion, the mathematical education of biologists should help in the following tasks:

1. It should give them an idea about the meaning of mathematical approaches that could serve to learn about quantitative patterns in biological phenomena.

2. It should teach them the fundamentals of processing experimental biological data.

3. It should teach them not to be afraid of mathematically formulated articles dealing with biology and of having a critical attitude toward the premises and mathematical system [structure] used in them.

4. It should give them an idea about the principles involved in building mathematical models of biological processes.

5. It should convince them of the benefits of professional collaboration with mathematicians on a regular basis, since they are capable of becoming interested in studying biological phenomena. This program does not by any means imply that a biologist is to change into a mathematician, and its purpose is to arm the biologist with mathematical methods.

The mathematical works of the biologist, N. A. Plokhinskiy, are rather similar in their initial premises to the general theses advanced in this foreword.

The textbook, "Algorithms in Biometrics," deals with the description and explanation of computing procedures that are needed to process statistical data as they apply to biological problems. The contents of this book are tied in with the author's well-known books, "Biometrics," "Manual of Biometrics," "Heredity" and enlarges upon his previously published book, "Algorithms of Biometrics" (1967).

The offered textbook is, in a certain sense, the concluding part of the many years N. A. Plokhinskiy worked on the use of classical methods of mathematical statistics and probability theory in biological research.

This book meets the pressing needs of biologists, and it is an excellent gift for the numerous students and followers of N. A. Plokhinskiy.

Introduction

An algorithm is the systematized description of a purposeful sequence of operations. [actions].

The algorithms furnished in this guide describe the form, order and formulas that are needed to find the most frequently used biometric parameters.

Mathematical methods, which have been modified to conform with specific objects and phenomena in life, as well as the distinctions of biological studies, are presently used in many branches of biology.

The questions of which mathematical methods, when and in what form they should be used, as well as the biological meaning of eventual results of calculations, are dealt with in the theoretical part of biometrics, and they are answered in accordance with the objectives of each specific study. After these questions are answered, we proceed to the practical use of the chosen methods, i.e., biometric processing of primary data.

This guide has as its purpose to organize, define and simplify the techniques for biometric calculations that are needed to analyze the results of experiments and observations, or when using production accounting records.

The algorithms submitted here are referable to methods that were chosen from the vast armamentarium of modern mathematics (probability theory, mathematical statistics and other branches), as being the most suitable for modern biological studies.

The major difficulty of preparing this textbook was in the choice of standardized (at least, within the framework of one manual) terms and symbols. It was found impossible to take an existing integral system, since such a system does not exist. Many various designations for the same parameters are used in works dealing with mathematics; there are seven different symbols to designate the arithmetic mean, nine different symbols for the sum of the squares of central deviations, six different terms for the concept of "reliability of difference," five different terms to designate the main property of any group consisting of dissimilar objects with reference to the tag under study.

Such a diversity of symbols and parameters can be easily attributed to the fact that the letters of three alphabets--Latin, Greek and Gothic--are not enough to designate the enormous quantity of mathematical parameters, so that it is impossible to assign a special symbol for each parameter. Mathematical schools and different mathematicians find a solution to this situation in their own and, of course, different ways. Some prefer to use the symbol M to refer to the mean, others prefer the square of the mean-square deviation. Some use the symbol V for the datum (result of primary measurement of an object), others use the symbol x, although it would seem that the symbol for an unknown or symbol of an argument should not be used for values that are known from the very start of a study and usually not viewed as arguments, but on the contrary as a function of the arguments studied, the influences.

In some cases, abstract mathematical terms lead biologists into error when studying specific phenomena. For example, designation of dissimilarity of objects in a group by the term "variability" (which refers to a very different phenomenon in biology) could lead to improper interpretation of the term "heritability."

In preparing this guide, we had to introduce designations that do not reflect any specific mathematical system of terms and symbols (there is no such system), but those that were the most suitable for biologists and corresponded rather accurately to the biological essence of a phenomenon or parameter.

The attached table is a brief summary of the main biometric terms and symbols.

Main terms and symbols used in biometrics

In this manual	In works of other authors
Tag [sign]--elementary distinction of each object on the outside, inside, in constitution, anatomy, histology, physiology, productivity	Random value, variable
Datum (result of measuring sign, its value, magnitude) V	Value acquired by random variable, variant V, X, x, y, a
Group size (number of objects in group) n, N	Size, volume of group n, N
Mean value of tag M = $\Sigma V/n$ General mean $\overline{M}$ Sample mean $\tilde{M}$	Mean value of random variable M, m, a, b, β, ε, $\overline{x}$
Diversity (presence of dissimilar objects in group)	Variability, fluctuation, dispersion and even "scatter"
Sum of squares, dispersion C = $\Sigma(V-M)^2$	Sum of squares of central deviations, sum of squares, dispersion: $\Sigma(V-M)^2$, $\Sigma(x-\overline{x})^2$, Σx^2, S, SS, SO, SA, SAQ, CQ
Variance, mean square $\sigma^2 = \frac{C}{n-1}$	Mean square, dispersion, deviation variance σ^2, S^2, ν^2, E, M, MQ, ES
Mean square deviation, sigma $\sigma = \sqrt{\frac{C}{n-1}}$ General sigma $\overline{\sigma}$, Sample sigma $\tilde{\sigma}$, S	Mean square deviation, standard σ, S, ν
Reliable difference (one can expect the same difference between general means as was found between sample means)--difference in sign, magnitude of difference, confidence limits $(\tilde{M}_1>\tilde{M}_2) \rightarrow (\overline{M}_1>\overline{M}_2)$	Substantial, reliable, significant, real, difference, there is a difference, "difference is reliable, i.e., real," samples from different general sets (?)
Unreliable difference (vague results were obtained) $(\tilde{M}_1>\tilde{M}_2) \rightarrow (\overline{M}_1 \gtrless \overline{M}_2)$	Insignificant, etc., difference. Samples from one general set (?)

Contents

10,657
CSO: 1840/999

BIOTECHNOLOGY

UDC: 576.8.095.5

SITE-SPECIFIC NATURE OF RECOMBINATION IN ESCHERICHIA COLI K-12 AND POSSIBILITY OF ELIMINATION OF 'HOT' SITES

Moscow DOKLADY AKADEMII NAUK SSSR in Russian Vol 257, No 6, 1981 pp 1466-1469

[Article by S. Ye. Bresler, S. V. Krivonogov and V. A. Lantsov, Leningrad Institute of Nuclear Physics imeni B. P. Konstantinov, USSR Academy of Sciences, Gatchina, Leningrad Oblast (presented by Academician N. P. Dubinin on 1 Dec 80), submitted 1 Dec 80]

[Text] After the work done by the team of A. Clark, it has now become apparent that an entire gamut of enzymes, products of recA, recBC, recF, sbcB and other genes, are involved in E. coli recombination. Clark et al. [1] introduced into the literature the concept of recombination pathways. Two of the most important ones are the RecBC pathway occurring in wild type cells, which is inhibited by a factor of $10^{1.5}$-10^2 in recBC$^-$ cells, and the RecF pathway which opens up in recBC$^-$ cells through additional mutation of sbcB$^-$, i.e., which excludes exonucleases 5 and 1. If we consider the absolute yield of recombinants after conjugation, recombination is quantitatively restored to virtually the level of cells of the wild type in the RecF pathway.

We used a different procedure for studying recombination in our work, namely, we studied linkage of markers or the scale of the genetic map. The latter describes recombination the most naturally, since it sets the mean number of recombination events per unit chromosome length. Scale λ is related to linkage coefficient μ on the basis of the formula of Haldane: $\mu = \frac{1}{2}(l + e^{-2l/\lambda})$, where l is the distance between markers on the E. coli map and $\mu = 1 - w$), where w is the standardized probability of recombination. When there are hot spots or regions of negative interference on the chromosome, scale λ becomes rather small, as compared to the mean value.

Such analysis enabled us to demonstrate that there are virtually no recombinant breaks in donor DNA in postconjugation merozygotes recF$^-$sbcB$^-$ [2]. This means that recombination processes occur only at the ends of the donor fragment, apparently due to endonuclease activity of recBC nuclease, which could emerge as recombination endonuclease, according to current conceptions [3]. In the described situation, the size of the integrated donor fragment is determined mainly by the process of breaking of donor DNA in the course of conjugation, and it can be made as large as one wishes.

A different phenomenon is observed in recBC$^-$sbcB$^-$ merozygotes. There, recombination is initiated in the middle of the chromosome in several hot sites, called

freI, freII and freIII. In them, the λ scale is 20 times smaller than the mean, i.e., the incidence of recombination exchanges is very high. For this reason, the genetic material is often eliminated from these sites with recombination. This process is particularly graphic if observed on a long F' transferring a chromosomal fragment from hot site freI [4]. Such an F' is extremely unstable, being subject to recA-dependent recombination dissociation into fragments in recBC$^-$sbcB$^-$ cells; it is more stable in rec$^+$ cells and absolutely stable in recBC$^-$sbcB$^-$recF$^-$ cells or single recF$^-$ mutants.

Hence, we conclude that the product of the recF gene is directly involved in site-specific recA-dependent recombination.

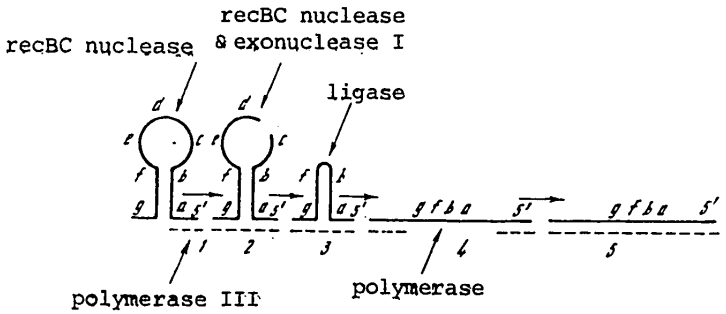
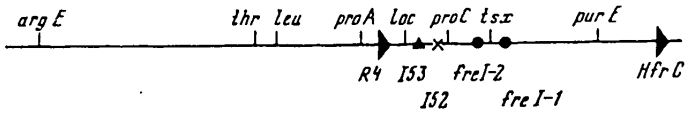


Figure 1. Elimination of hairpin fre site under the influence of nucleases in the course of conjugation

1) site structure after transfer of single-stranded donor DNA to recipient; dotted line--conjugational DNA synthesis in recipient, loop is attacked by nuclease with single-stranded endonuclease activity
2) degradation of hairpin by nucleases
3,4,5) subsequent stages of site elimination



Fiugre 2. Fragment of E. coli map [8]. Start of transfer of chromosome from R4 and HfrC donors, localization of freI1 and freI2 sites, as well as IS elements [9], are shown

But what happens in wild type cells? Apparently, the primary breaks in donor DNA are initiated by the same recF-dependent endonuclease, but then the fragments undergo intensive degradation at the ends under the influence of exonucleases 5 and 1. As a result, the most varied fragments of donor DNA, which are distributed according to the law of chance (Poisson distribution of lengths), are integrated in the chromosome of the recipient and the effects of the hot spots are blurred.

In view of the foregoing, it is more correct, in our opinion, to refer to expression of pure RecBC pathway in recF⁻sbcB⁻ cells, pure RecF pathway, as before, in RecBC⁻sbcB⁻ cells and combined RecBCF pathway in cells of the wild type. The biological purpose of different pathways is differentiation of specificity of endonucleases (recBC nuclease and recF-dependent endonuclease) that determine them. RecBC nuclease initiates recombination for chi sites that are multiple markers of the E. coli chromosome [5] and recF-dependent nuclease does so for fre sites that are scattered over the chromosome, but grouped in freI, II and III sites.

What is the structure of the fre sites? For the time being, we have no direct evidence, but indirect observations indicate that these sites of protein and nucleic acid recognition could be paindromic, i.e., hairpin structures. In the first place, when the F' plasmid recombines with the cell chromosome, elimination of a piece from the chromosomal part of the plasmid does not prevent it from reclosing into a circular structure [2], which is no doubt effected by means of countercomplementary DNA sites. In the second place, mobilization of the cell chromosome by the F factor occurs with a high degree of probability only in cells of the RecF pathway and at the same points on the map where stable Hfr can be formed [4]. Consequently, the hot spots of recombination are demonstrable, in this instance, among IS2 and IS3 elements, according to which, as we know, there is interaction between the F factor and the chromosome. At the ends of these same elements, as well as other IS elements that have been studied, extensive countercomplementary sequences have been demonstrated [6, 7]. Finally, we can anticipate the following typical distinction of the paindromic sites: the possibility of their disappearance without affecting viability of the cell. The experimental data submitted below indicate that in the course of conjugative passage of the entire donor chromosome through the cytoplasm of the rec⁺ recipient, but not recBC⁻sbcB⁻, the hot sites of recombination that are scattered over its chromosome are "eaten up" by exonucleases 5 and 1 as illustrated, for example, in Figure 1.

Upon conjugation, donors HfrC and R4 transfer their chromosomes in the same direction, but in such a way that only the first will transmit the freI site with hot spots of recombination (Figure 2). This is reflected in the dependence of the coefficient of marker linkage μ on distance between them, which is illustrated in Figure 3 in a form that is convenient for graphic determination of parameter λ. As can be seen, the R4 donor on the RecF recombination pathway has a constant and large λ scale, i.e., recombination exchanges between the donor chromosome fragment and recipient chromosome in conjugative merozygotes are distributed rather uniformly over the chromosome, and they occur relatively seldom. The situation with the HfrC donor is different. There the λ scale is small, and it diminishes as we approach the freI hot site, which reflects the effect of recombination hot sites.

Hfr CAB-5 donor was obtained by means of conjugative passage of the entire HfrC donor chromosome thorugh the AB1157 rec⁺ recipient. As can be seen in Figure 3, it shows a decrease in incidence of recombinant exchanges in the afgE-proA region of the E. coli map (even in comparison to the R4 donor) and an 8-fold increase in λ scale in the freI region, as compared to the HfrC donor, i.e., the recombinant capacity of the HfrC donor chromosome underwent substantial changes in the CAB-5 variant, and they are related expressly to the effects of exonucleases 5 and 1 on the original HfrC donor chromosome. Indeed, analagous passage of the chromosome from the same donor through recipient JC7623 wanting in these nucleases led to selection of Hfr CJC donors demonstrating the same dependence of coefficient μ on distance l as for the original HfrC donor.

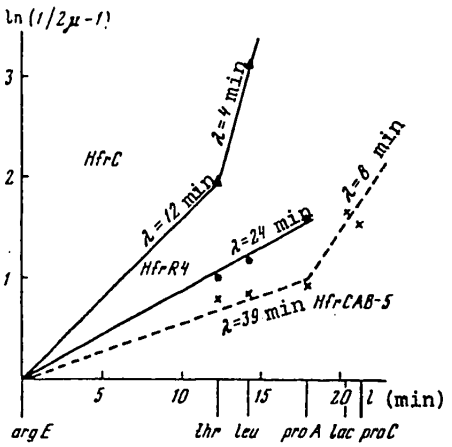


Figure 3.
Determination of λ scale of genetic map according to linkage coefficient μ of the selection marker arg E with non-selection markers, which are shown on the x-axis; l is distance between markers in minutes of the E.coli map;results of crossing recipient Jc7623 recBC⁻sbcB⁻ with donors HfrC, R4 and CAB-5 are illustrated.

The next two observations confirm the unique recombinant properties of the Hfr CAB-5 donor.

Exconjugants of the REcBC pathway integrate the fragment of donor DNA mainly by means of recombinations on the edges of the fragment. This effect should be manifested the most vividly for the CAB-5 donor that has lost part of the fre sites. Indeed, crossing CAB-5 with ECK 035 recF⁻sbcB⁻ demonstrated linkage between lac and metB markers μ = 0.96, i.e., a fragment of donor DNA one-quarter the size of the chromosome is entirely integrated in the recipient chromosome.

The hot recombination sites are involved in mobilization of the chromosome by factor F. If a DNA fragment without fre sites is transferred from a CAB-5 donor to a JC7623 recipient and factor F is introduced into the obtained transconjugant JC7623 thr⁺leu⁺proA⁺ (JC+++), the mobilization characteristics of the transconjugant should differ from those previously demonstrated for ordinary recipients, for example, ECK 065:JC7623 leu⁺ [4]. Indeed, the ratio of yield of recombinants referable to brief mobilization of donor ECK 065 F⁺leu⁺:proC⁺:purE⁺ = 1:3:3 changed for two independently selected JC+++ donors for the above-mentioned markers to 0.1:3:2.7 and 0.1:3:3, respectively, i.e., mobilization in the region of the leu marker, where the hot spots were eliminated after arriving in the rec⁺ cell, decreased by a factor of 10.

All these data confirm the substantial decrease of site-specific recombinatorial capacity of the chromosome of the CAB-5 donor. It is logical to interpret this phenomenon as nuclease degradation of the structure of the fre sites. This, in turn, leads to two important conclusions: 1) the fre sites are not essential to viability of the cell; 2) the structure of expressly donor DNA determines the frequency of recombination exchanges with the recipient chromosome and, consequently, expressly donor DNA is responsible for initiating postconjugation recombination.

BIBLIOGRAPHY

1. Clark, A. J., ANN. REV. GENET., Vol 7, 1974, p 67.

2. Bresler, S. E., Krivonogov, S. V. and Lanzov, V. A., MOL. GEN. GENET., Vol 116, 1978, p 337.

3. Rosamund, D., Telander, K. M. and Linn, S., J. BIOL. CHEM., Vol 254, 1979, p 8646.

4. Bresler, S. E., Krivonogov, S. V. and Lanzov, V. A., MOL. GEN. GENET., Vol 177, 1979, p 177.

5. Stahl, F. W., ANN. REV. GENET., Vol 13, 1979, p 7.

6. Ghosal, D. and Saedler, H., NUCL. ACID RES., Vol 6, 1979, p 1111.

7. Starlinger, P., PLASMID, Vol 3, 1980, p 241.

8. Bachmann, B. J., Low, B. K. and Taylor, A. L., BACTERIOL. REV., Vol 40, 1976, p 116.

9. Deonier, R. C., Oh, G. R. and Hu, M., J. BACTERIOL., Vol 129, 1977, p 1129.

10,657
CSO: 1840/253

CHAPTER 4. CULTURE OF MICROALGAE AS THE REGENERATING ELEMENT IN A BIOLOGICAL LIFE SUPPORT SYSTEM FOR MAN

Novosibirsk ENERGETIKA FOTOSINTEZIRUYUSHCHEY KUL'TURY MIKROVODOROSLEY in Russian 1980 (signed to press 2 Jan 80) pp 93-123

[Chapter from book "Activity of a Photosynthesizing Culture of Microalgae", by Vladimir Nikolayevich Belyanin, Fedor Yakovlevich Sid'ko and Anton Pavlovich Trenkenshu, Institute of Physics imeni L. V. Kirenskiy, Siberian Department of the USSR Academy of Sciences, Izdatel'stvo "Nauka", 1000 copies, 136 pages]

[Text] 4.1. Preliminary Remarks

It is known that human life support systems (LSS) with minimal power consumption, weight, size and technologically the most efficient ones for short-term space flights, lasting up to several dozen days, are based on onboard supplies. In the case of flights of average duration (over 1 month and up to 1.0-1.5 years) the required economy of LSS is provided by using physicochemical regeneration of water from the condensate of atmospheric moisture and liquid excretions of man with concurrent regeneration of carbon dioxide (CO_2) sorbent [115]. For longer space missions lasting 1.5-2 years, from the standpoint of energy, it is desirable to perform physicochemical regeneration of oxygen from CO_2 and metabolic fluid, in addition to regeneration of water.

During such missions, biological regeneration of substances in manned spacecraft is considered inexpedient, mainly because of the energy required and initial weight. But when interplanetary missions last more than 2-3 years, as well as for long-lived planetary stations that are manned, the biological life support system (BLSS) is advanced to the fore among other types of systems. This is related exclusively to the need to produce food in spacecraft, which can be obtained in the traditional form and composition only on the basis of biosynthesis in the foreseeable future [116].

However, the sooner different versions of BLSS are comprehensively developed and reach acceptable limits of energy requirements and weight, the sooner the biological method of regeneration could be used to good advantage in spacecraft and manned space stations, either along with physicochemical systems or as part of them. This applies primarily to the use of solar energy.

When developing various LSS, the initial specifications are referable to minimal use of energy, size and initial weight for a specified period of reliable operation of the system. These criteria will also be the decisive ones in the future. For

this reason, consideration of energetics and corresponding mass transfer of a BLSS that is the simplest in composition and intrasystemic relations, containing a culture of photoautotrophic microorganisms (microalgae) as the only regenerator, is believed to be one of the priority tasks, primarily with reference to furnishing light for the cell culture.

In theory, the use of plants in BLSS permits complex regeneration of substances (gas, water, food) in a single biosynthetic (and technological) process, based on human metabolites. To date, microalgae cultures as a structurally simple element of BLSS have been developed the most with regard to regeneration of gas and water. Taking also into consideration the high biological stability and significant energy efficiency of photobiosynthesis (14-18%) obtained in experiments with a controlled culture of microalgae, as well as the energy and mass transfer in this element, which has been firmly established in experimental ecological systems, there are sufficient quantitative prerequisites to design [evaluate] different promising versions of BLSS with algae to regenerate gas, water and, in part, food. The energetics of such variants, based mainly on the use of photosynthetically active radiation directly from the sun are quite similar in parameters to energetics of physicochemical LSS.

The situation is not as definitie with regard to reproduction of satisfactory food by means of biosynthesis of microalgae as it is with respect to regeneration of gas and water on the basis of human metabolites. However, there are no grounds to believe that this problem cannot be solved in the foreseeable future. It should be noted that the efforts applied to solve this problem heretofore were generally insignificant, as compared to its complexity. Among studies in this direction, there are several we can single out [117-119].

One of the most important questions of the food aspect of BLSS based on algae is to find an effective means of transforming and processing algal biomass and products derived from algae that would improve significantly their assimilation in the human body. Ultimately, the use of a broad spectrum of algal species from different systematic groups could solve this problem.

If it is necessary to reproduce in the BLSS foods of animal origin, most of the microalgal biomass could be used well as animal feed. However, it should be noted that this would lower drastically the overall energy efficiency of the system.

Aside from the energy-related aspects of development of BLSS with microalgae, we can list a few others, which may be of substantial importance to studies in space. One of them consists of the fact that, by virtue of the rapid growth of microalgae (up to 9-fold increase in number and biomass per day in a stationary growth process), they can be used to rapidly determine the causes of possible instability of BLSS functions in the space environment related to the process of plant and microorganism biosynthesis. Concurrently, the faster the rate of regeneration processes, the smaller the weight and size of the system element. In general, microalgal cultures are a productive and, in many respects, convenient experimental model of the phototrophic element of a BLSS, which saves time in studying many variants of the system with plants and microorganisms, permits evaluation thereof with regard to energetics, photosynthetic stability and other characteristics under specific conditions. If necessary, one can create a phototrophic element on the basis of a microalgal culture that would have the utmost biological resistance to cosmic factors that cause the death of most other organisms.

Safety and reliability of the organism populations used, the rapidity of restoration of their regenerative functions and other features, which are attributable, as we have already mentioned, to their rapid growth and the fact that these organisms are unicellular and numerous, are among the most important features of a BLSS that contains algae. Thus, the entire program of reproduction and biosynthetic processes, which are necessary for algae to perform regenerative functions in a BLSS, is contained in each cell the size of several cubic microns, and there are more than 10^{13} cells in this component of the system.

All of the additionally noted distinctions of BLSS imply provisions for economical energy metabolism of the system, which is largely related to the use of a culture of microalgae as the component or its model. Quantitative estimation of the energy of such a component is also interesting in view of the fact that, to date, several species of algae from different systematic sections have been well-studied, along with chlorella, with respect to photoenergetics and consideration of LSS requirements. Successful regeneration of gas and water on the basis of microalgal photobiosynthesis is a fact that has been established in many tests with an experimental closed ecosystem including man (ECES), and there are conforming data concerning energy and mass transfer of their components [120-125]. In these experiments, convincing demonstration was made of the biological compatibility of algae and man; the technology and technical execution of the regeneration process in the phototrophic component have been refined, and this is the basis for all subsequent quantitative evaluations of algae in the matter of implementing the closed cycle of substances in artificial systems.

Thus, the research and technological development of a two-component BLSS, consisting of man and a culture of microalgae, has reached a level that permits making calculations and providing a quantitative assessment of energy efficient variants with equiponderant energy and mass transfer of components in the system.

Hereafter, we shall deal mainly with human trophoenergetics, photoenergetics of cultures of different species of microalgae and mass transfer parameters related to energy transfer of their elements.

4.2. Base Data on Energy and Mass Metabolism [Exchange] of the Human Body

Man's total energy expenditure (Q_{man}) during space flight determine the main characteristics of the LSS, including productivity of the algal culture that is required for balanced gas exchange in the biological system. Many data have been accumulated on Q_{man} in relevant ground-based complexes, ECES and directly in spacecraft. Thus, during flights aboard Soviet spacecraft of the Vostok type, the energy expended by cosmonauts constituted 2040-2340 kcal/day, whereas for American cosmonauts aboard the Gemini type of spacecraft Q_{man} ranged from 2010 to 2410 kcal/day in different flights [126].

Extravehicular activity in space will require more expenditure of energy by man than in a spacecraft or on the moon's surface, and it is estimated at about 2700 kcal/day during moderate work by a cosmonaut [126]. In our subsequent quantitative investigation of a two-component BLSS, we use a value of Q_{man} of about 2800 kcal/day, in accordance with the data in [127]. This level enables us to assess the capability of a system that could be used in practice for the

performance of diverse programs in space. It is considered that a cosmonaut weighing 70 kg develops an average power of 136 W in a spacecraft or orbital station.*

The free energy from assimilated food is the source of man's energy expenditure. Food energy is released in the body with uptake of O_2 and concurrent output of CO_2 and fluid in the course of biological oxidation of nutrients.

First, we must determine the amount of O_2 needed for oxidation of the ration with assimilated energy of 136 W (2806 kcal/day). This can be calculated on the basis of the biochemical composition of food, levels of protein, fats and carbohydrates in it as the main and nonspecific sources of energy for man.

We use the balanced diet ration [128] to determine and evaluate metabolic parameters related to assimilation of food as the "standard" ratio [128]. According to the formula for a balanced diet, the proportion of proteins to fats and assimilable carbohydrates constitutes 1:1:5 or 14.3, 14.3 and 7.14%, respectively. In space, it is recommended that this ratio be held at 1:1:3 [126]. In general, there is a wider range of variation of carbohydrates than protein and fats.

The balanced diet contains 670 g anhydrous substance, of which 655 g (97.8%) is referable to organic matter and 15 g to mineral compounds (Table 1). If we consider only assimilated carbohydrates, together with protein and fats, the total amount of substance--the complete source of energy for the body--would constitute 630 g, or 96.2% of all organic substances in the diet (25 g inert carbohydrates subtracted).

Table 1. Composition of balanced diet according to the formula given in [128]

Constituents	Assimilable amounts, g/day	% of weight of anhydrous matter	g/day
Protein	90	13.4	Plant origin, 40 (44.4) Animal, 50 (55.6)
Fats	90	13.4	Plant, 22.5 (25)
Carbohydrates	475	71.6	Assimilable (starch, mono- and disaccharides), 450 (94.7) Inert (cellulose, pectin), 25 (5.3)
Organic acids (citric, lactic and others)	2.0	--	(2 g included in total weight of assimilable carbohydrates)
Vitamins (A, B_1, B_2, B_3, B_6, B_{12}, C, D, E, K, H, P, PP, inositol, choline, lipoic acid, carotenoids)	1.6		(1.6 g included in total weight of protein and fats)
Minerals (sodium, chlorine in chlorides, calcium, phosphorus, potassium, magnesium and others)	15	2.2	--

Note: Chlorine in mineral was determined from NaCl content. Percentages are given in parentheses in the last column).

*This can be defined as the energy constant for the human body under the conditions discussed.

The ratio of protein to fats and total carbohydrates of all types (assimilable and inert) is 1:1:5.3 in the anhydrous substance of the balanced diet.

We can note the significant amount of protein and fats of animal origin, up to 75% of the total weight of the ration, as a distinction of the diet in question.

Fats have the highest energy of all constituents of food, and a change in amount thereof has a noticeable effect on man's energy supply. The energy value of fats when they are oxidized in the body constitutes 9 kcal/g, versus 4 and 3.7 kcal/g for protein and assimilable carbohydrates. If we use these coefficients (Δq), it is not difficult to determine the share of each of these constituents of assimilated food in providing all energy expenditures of man. The energy value Δq of fats, protein and carbohydrates, their assimilability (η_g by weight) and latent combustion heat (ΔH) (Table 2) enabled us to determine the share of each constituent in assimilable energy and caloric value of the balanced diet. Inert carbohydrates are listed as cellulose, for which $\Delta H \simeq 4.2$ kcal/g [129].

Table 2. Energy characteristics and assimilability of the balanced diet (mean values)

Constituents	g/day	Latent combustion heat ΔH kcal/g	Complete oxidation energy q_R kcal	Complete oxidation energy q_R % of total	Assimilabil. (by wt.) ηg/%	Energy value Δq, kcal/g	Relat. energy $\pi = \frac{\Delta q}{\Delta H}$ %	Assimilable energy, gF kcal	Assimilable energy, gF % of total	Assimil. (from energy) $\eta q = \frac{qF}{q_R}$
Protein	90	5,65	508,5	16,2	84,5	4,00	70,8	304,2	11,0	59,8
Fat	90	9,35	841,5	26,7	94,0	9,00	96,2	761,4	27,5	90,5
Carbohydrates (assimilable)	450	3,75	1687.5	53,7	100,0	3,75	100,0	1687,5	61,0	100,0
(Organic matter G, protein, fat and assim. carbohydr.)	630	4,82	3037,5	96,6	96,9	4,51	93.6	2753,1	99,5	90,6
Carbohydrates (assim. & inert)	475	3,78	1794,3	57,1	95,6	3,75	99,2	1692,5	61,5	94,9
			Integral parameters							
Organic matter in diet as a whole	655	$\overline{\Delta H}$ 4,80	Q_R 3144,3	100	η_G 93,8	$\overline{\Delta q}$ 4,50	$\overline{\pi}$ 93,7	Q_F 2768,1	100	η_Q 88,0

Thus, the assimilable carbohydrates of the balanced diet furnish an average of 61% of the body's energy, fats furnish 27.5% and protein 11%. On the whole, the organic matter of the balanced diet has an energy value of $\overline{\Delta q} = 4.50$ kcal/g. In this matter, the energy of proteins is assimilated with the least efficiency (59%) due to its incomplete oxidation in the body. About 30% of all energy contained in food protein is excreted in urine urea.

In the general case, the energy assimilated by the body can be determined with sufficient accuracy as the difference between caloric value of food taken and energy content of liquid and solid excretions. It is interesting to compare the

weight and energy indicators of the balanced data to those of the ECES (Table 3, base data of Yu. N. Okladnikov). The results listed in Table 3 are referable to man's intake of food and experimentally measured assimilation (by weight) of its main constituents. The energy parameters of the experimental diets were calculated using the same values of nutrient energy that are listed for the balanced diet (see Table 2).

Table 3. Weight and energy parameters of organic matter in diets used in experiments with ECES, consisting of man and plants [120, 123, 130, 124, 131], with data for balanced diet given for comparison

Experim. No	ECES structure and duration of experiments (days); balanced diet	Constituent	Expendit. of g, g/day		Shares of energy in diet, %	
					in consumed food, q_R	in assimilated food, q_F
1	Man-microalgae (30)	Protein	88	—	—	—
		Fat	85	—	—	—
		Carbohydr.*	250	—	—	—
2	Man-microalgae (45)	Protein	78	81,0	20,7	13,9
		Fat	82	93,0	35,9	37,7
		Carbohydr.	245	96,0	43,4	48,4
3	Man-microalgae-higher plants-microbial culture (90)	Protein	76	86,8	20,1	13,8
		Fat	73	97,3	31,9	33,4
		Carbohydr.	271	99,3	48,0	52,8
4	Man-microalgae-higher plants (180) phase 3	Protein	107	93,4	22,0	16,2
		Fat	77	96,1	26,3	27,3
		Carbohydr.	375	99,7	51,7	56,8
5	Man-higher plants (120)	Protein	106	84,9	20,9	14,4
		Fat	102	93,1	33,2	34,2
		Carbohydr.	349	98,0	45,9	51,4
	Balanced diet (average levels and range of variation)	Protein	90 (80—100)	84,5	16,2 (13,4—19,4)	11,0
		Fat	90 (80—100)	94,0	26,7 (22,7—31,4)	27,5
		Carbohydr.	475 (425—525)	95,6	57,1 (51,5—62,3)	65,1

*Assimilated and inert carbohydrates together.

As compared to the balanced diet, it should be noted that in the experiments with ECES diets with high protein content were mainly used, and it constituted 20-22% of the total calories of ingested food (versus 16.2% with the balanced diet) due to some decrease in carbohydrate content. It is opportune to mention here that an increase in protein content of the human diet is inherent in manned space flights.

The above-mentioned differences in the diets determined the values of integral coefficients η_Q and $\overline{\Delta q}$ for them. The value of η_Q was affected mainly by the share of assimilated energy from protein and that of $\overline{\Delta q}$ by the proportion of energy from carbohydrates and fats, being the most different constituents of the diet with respect to energy value (Table 4).

Figure 49 illustrates the curve of $\overline{\Delta q}$ as a function of proportion of energy (ξ) from assimilated carbohydrates and fats. This function was found for two fixed levels

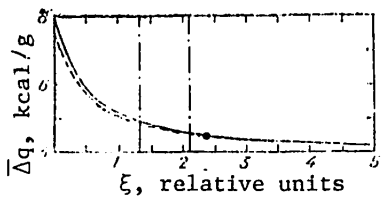


Figure 49.
Energy ($\overline{\Delta q}$) of diet as a function of proportion of assimilated carbohydrates and fat (ξ) in the diet (for energy): continuous line--for q_F^{prot} = 0.11 and dash line--for q_F^{prot} = 0.14

of protein [prot] in organic matter, constituting 11 and 14% of energy of assimilated food (q_F^{prot}). Such levels are inherent in the balanced diet and, on the average, for the experimental diets used in ECES (see Tables 2 and 3), and they conform with vital functions of a nongrowing organism, which meets the adopted base requirements for LSS.

The distinctive feature of the function illustrated in Figure 49 for $\overline{\Delta q}$ is that displacement of the curves is seen only in the region of low values of ξ, which are not of practical value and, moreover, do not exceed 3.5% for the two protein levels considered. The cause of this is that the values of Δq for protein and carbohydrates differ relatively little from one another, but substantially (by 2.25 and 2.40 times) from Δq for fats.

Thus, it can be concluded that for ξ in the range of 1.2-3.5, the range of protein content can be widened somewhat, for example, to 8-15% according to energy, without a significant influence on the values of $\overline{\Delta q}$ (see Figure 49).

Table 4. Total organic matter in diet

Exper. No	Total energy in consumed diet, Q_R	Latent combust. heat $\overline{\Delta H}$	Energy value $\overline{\Delta q}$	Assimil., %		Total assimilated energy, Q_F, kcal/day
		kcal/g		by wt. η_G	by energy η_Q	
1	—	—	—	—	—	—
2	2133,5	5,27	4,86	92,5	85,35	1821,1
3	2136,3	5,09	4,71	96,7	89,5	1912,3
4	2742,0	4,90	4,50	98,0	90,0	2467,7
5	2871,8	5,16	4,74	94,6	87,0	2497,2

Note: To calculate the energy parameters of the diet, the values of ΔH and Δq for different organic substances were taken from Table 2.

For diets tested in ECES, it was found that the increase in values of $\overline{\Delta q}$ (as compared to a balanced diet) are attributable chiefly to the larger share of fat in assimilated food due to overall decrease in carbohydrates.

Within the range of practical values of ξ linear approximation of function $\overline{\Delta q}$ (kcal/g) is possible:

$$\overline{\Delta q} = 5{,}1 - 0{,}25\,\xi, \text{ for } 1{,}2 < \xi < 3{,}5;\ 0{,}08 < q_F^{prot} < 0{,}15. \qquad (4.1)$$

Equation (4.1) establishes a simple quantitative relationship between the biochemical composition of the diet (main constituents) and its specific energy value, and it is referable to assimilated food. When we turn to ingested food, we must use the coefficients of energetic assimilability (Table 5).

Table 5. Mean levels and range of changes in assimilation of diet according to results of experiments in ECES (%)

Assimilation coefficients	Diet constituents			Total organic matter
	protein	fat	carbohyd. (all types overall)	
By wt., η_g	86,5 (81÷93)	94,9 (93÷97)	98,2 (96÷100)	—
By energy, $\eta_q = \eta_g \frac{\Delta q}{\Delta H}$	61,2 (57÷66)	91,3 (89÷94)	97,5 (95÷99)	—
By wt., η_G	—	—	—	95,4 (92÷98)
By energy, $\eta_Q = \eta_G \frac{\overline{\Delta q}}{\Delta H}$	—	—	—	87,9 (85÷90)

If we consider the level of assimilation referable to a balanced diet (see Table 2), the experimental values of coefficients must be adjusted for use in calculations. Hereafter, we shall use the following approximate values for coefficients of assimilation (%): for protein, $\eta_g^{prot} = 85.5$, $\eta_q^{prot} = 60.5$; for fats $\eta_g^{fat} = 94.5$, $\eta_q^{fat} = 91.0$; for carbohydrates $\eta_g^{car} = 96.5$ and $\eta_q^{car} = 96.0$.

When determining the main parameters of mass transfer associated with energy in the human body, along with assimilation we must know specific uptake and output of O_2 and CO_2 upon oxidation of different constituents of food.

It is known that carbon-hydrogen bonds in organic matter of the diet serve as the chief source of energy for energy-consuming processes. The energy of these bonds is released as a result of oxidative reactions that utilize O_2 and release CO_2 and H_2O. The overall energy thus released is unrelated to the type of intermediate reactions or their products, but is entirely determined by the initial and final structure of substances assimilated in the body [132]. Accordingly, one observes a stoichiometric relationship between the energy value $\overline{\Delta q}$ of organic matter in food, O_2 uptake, CO_2 and H_2O output, which can be determined from the specific outlay of O_2 and respiratory quotients (RQ) for protein, fats and carbohydrates oxidized in the body [133, 134].

With reference to the experiments with ECES, the values of the coefficients used were taken from the work of Zbarskiy et al. [134]. RQ, specific expenditure of O_2 (Δg_{O_2}) and output of metabolic water (Δg_{H_2O}) used for the main constituents of the diet showed a good agreement of estimated results with measured amounts of gases during the experiments [9] (Table 6). The integral oxycaloric ($\overline{\Delta q_{O_2}}$) and respiratory ($\overline{RQ}$) quotients found from them for different diets are illustrated in Figure 50 as a function of proportion of carbohydrates and fats in assimilated matter, ξ.

When protein content of the diet changes from 11 to 14%, the values of $\overline{\Delta q_{O_2}}$ and $\overline{RQ}$ differ insignificantly for energy (by no more than 0.5%) over a wide range of values of ξ. Even in the absence of protein in the assimilated ration (dotted line in Figure 50), as compared to $q_F^{pro} = 0.14$ the deviations for $\overline{RQ}$ do not exceed 2.5%. One can determine the values of gas exchange parameters of the body for diets with specified biochemical composition from the curves in Figure 50 and data in Table 6.

Table 6. Mass transfer coefficients for the process of oxidation of diet constituents in the human body [134]

Coefficients	Assimilated nutrient		
	protein	fat	carbohydr.
Specific uptake of O_2, Δg_{O_2}:			
$\ell^* O_2/g$	0,966 (0,987)	2,019 (2,024)	0,829 (0,827)
$g\ O_2/g$	1,380 (1,411)	2,885 (2,892)	1,185 (1,181)
Respiratory quotient (RQ):			
$\ell\ CO_2/\ell\ O_2$	0,801 (0,815)	0,707 (0,708)	1,00 (0,997)
$g\ CO_2/g\ O_2$	1,108 (1,127)	0,978 (0,980)	1,363 (1,379)
Specific output of metabolic H_2O, Δg_{H_2O}:			
$g\ H_2O/g$	0,41 (0,406)	1,07 (1,06)	0,60 (0,55)

Note: We used the following values for gas density (ρ) in our calculations: $\rho_{O_2} = 1.42896$ g/ℓ*, $\rho_{CO_2} = 1.9768$ g/ℓ*, where ℓ* is liter of corresponding gas under standard conditions (0°C, 760 mm Hg). Values calculated with the balance equation for oxidation of casein, triolein and starch are given in parentheses (per gram organic matter).

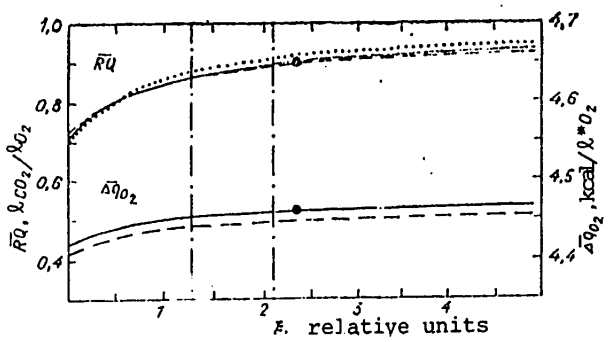


Figure 50.
Integral respiratory ($\overline{RQ}$) and oxycaloric ($\overline{\Delta q}_{O_2}$) quotients for assimilated diet as related to different proportions (for energy) of carbohydrates and fats (ξ). Designations of the curves are the same as in Figure 49.

These quotients and parameters of mass and energy transfer in man, which are related to assimilation of the diet, are referable to equiponderant metabolic processes, without transformation of different organic substances into others and subsequent accumulation or decrease thereof in the body.

If we were to select $\xi = 1.5$, which is close to the mean value for the diets used in experiments with ECES (see Table 3), the base coefficients for calculation of total amounts of energy involved in conjugate energy and mass transfer, based on data in Figures 49 and 50, will take on the following values: $\overline{RQ} = 0.870\ \ell\ CO_2/\ell\ O_2$ or $1.203\ g\ CO_2/g\ O_2$; $\overline{\Delta q} = 4.74$ kcal/g; $\overline{\Delta q}_{O_2} = 4.44$ kcal/ℓ* O_2 or 3.11 kcal/g O_2.

Caloric coefficient $\overline{\Delta q}_{H_2O}$ for metabolic water eliminated in the process of oxidation of food was found to equal 7.25 kcal/g H_2O. Protein content of the diet corresponds to 14%, with regard to supply of energy to the body, which conforms with the levels adopted in the USSR: 12-14% of total energy expenditure [126]. Of the energy received from such a diet, 34.3% is referable to oxidation of fats and 51.7% carbohydrates. As to weight of constituents of the assimilated organic matter, protein constitutes 16.6%, fat 18.1% and carbohydrates 65.3%.

We can calculate $\overline{RQ}$, $\overline{\Delta q}$, $\overline{\Delta q}_{O_2}$ and $\overline{\Delta q}_{H_2O}$ with other values of ξ without changing the method of calculation, from the data in the above tables and curves.

In this regard, it is interesting to consider the possibility of regulating $\overline{RQ}$ in practice by altering the biochemical composition of man's diet, i.e., by varying in the physiologically permissible range of values. Such regulation was made in several of the above-mentioned experiments with ECES. It can also be quantitatively estimated from the data in Figure 50.

One can use the equation of mass [mattter] balance on the basis of the established values of mean daily energy expenditure by man Q_{man} and biochemical composition of assimilated food (according to ξ and q_F^{prot}), and using the obtained values of $\overline{RQ}$, $\overline{\Delta q}$, $\overline{\Delta q}_{O_2}$ and Δq_{H_2O} (see preceding page) of amount of organic matter and O_2 needed for oxidation, as well as discharged CO_2 and H_2O:

$$Q_{man}\left(\frac{1}{\overline{\Delta q}}+\frac{1}{\overline{\Delta q}_{O_2}}\right)=Q_{man}\left(\frac{1}{\overline{\Delta q}_{O_2}}\cdot\overline{RQ}+\frac{1}{\overline{\Delta q}_{H_2O}}\right)+C, \qquad (4.2)$$

where C refers to the oxygen-containing mineral compounds in the experiments, but mainly organic matter that has undergone incomplete oxidation. In essence, they are phosphates, sulfates and urea, which are formed during protein metabolism and excreted in urine.

Equation (4.2) shows that with Q_{man} = 136 W and ξ = 1.5, 592 g of asssimilable organic food is required for a man weighing 70 kg, or, using the corresponding value of η_C = 0.941 (629 g organic matter in assimilated diet). The biochemical composition of such a diet is determined by the value of ξ and coefficients η_g listed above.

For oxidation in the body of the above-mentioned organic matter in the diet there will be expenditure of 631.6 ℓ* (902.5 g) O_2 per day. Concurrently, there will be output of 549.3 ℓ* (1085.8 g) CO_2 and 387 g H_2O, as well as 15.5 g total nitrogen (N_{tot}) with liquid excreta containing 28.5 g urea. The amount of N_{tot} and urea excreted in the case of partial oxidation of protein in the human body is determined from the results of experiments with ECES (see Tables 3 and 4).

Let us check the obtained indicators of mass transfer by means of the equation that describes the oxidation process and element formulas for different constituents and all of the organic matter in the diet.

For animal protein--casein--the element formula for the conventional unit, according to the experimental results in [125], has the following appearance: $C_{6.0}H_{9.50}O_{1.90}N_{1.53}$.

According to the same results, the formula for a typical fat--triolein--is $C_{6.0}H_{10.95}O_{0.63}$ and for the main carbohydrate in the diet--starch--$C_{6.0}H_{9.93}O_{5.00}$. In the last formula, due consideration was given to the fact that the amylopectin contained in starch (over 76%) has a larger amount of glucoside bonds than amylose, which is the second component of starch [135], and for this reason the number of hydrogen atoms (in relation to oxygen) is somewhat lower in starch than in glucose.

Use of the above formulas for casein, triolein and starch to describe the reaction of oxidation thereof leads us to the corresponding values of mass transfer

coefficients (see Table 6). On their basis, we can obtain the overall formula for all organic matter with specified ξ (1.50) and q_F^{prot} (0.14): $C_{6.0}H_{10.13}O_{3.29}N_{0.264}$.

The balance equation for the process of oxidation of 592 g of such matter is:

$$4{,}27\ C_{6{,}0}H_{10{,}13}O_{3{,}29}N_{0{,}264} + 28{,}626\ O_2 = 25{,}056\ CO_2 + \\ + 20{,}500\ H_2O + 0{,}564\ NH_2CONH_2 + 0{,}125\ \{O\}, \qquad (4.3)$$

where {O} is oxygen contained in phosphates and sulfates, or in mineral products of protein oxidation; the amount thereof in human liquid excreta (scaled to P_2O_5 and SO_3), determined from the data in [126], constitutes about 12.7% of total urine nitrogen.

It is easy to find from equation (4.3) that $\overline{RQ}$ = 0.780 ℓ CO_2/ℓ O_2, or 1.204 g CO_2/g O_2, with overal O_2 uptake in an amount of 641 ℓ* (916 g) per day; outputs of CO_2, water and urea constitute 558 ℓ* (1103 g), 369 g and 33.9 g, respectively. With the exception of $\overline{RQ}$ and metabolic fluid, all other parameters are appreciably higher than the values obtained with equation (4.2). First of all, it should be noted that other (with the exception of urea) nitrogen-containing substances excreted in urine, which generally have higher relative concentrations of carbon and oxygen, creatinine, hippuric and uric acid, purine bases, amino acids, phenols, organic acids, etc., which could total 13% of the total weight of urea [136], were not taken into consideration in the calculations. This could very well have caused the above-mentioned discrepancy between mass transfer values.

The overall element formula for all organic compounds, which are additional products of protein metabolism, without urea and oxygen in phosphates and sulfates, was determined from the results of analysis of urine element content [137]: $C_{4.0}H_{6.63}O_{1.44}N_{1.66}$. The established composition of additional nitrogen-containing substances enables us to obtain virtually complete agreement between estimated and experimental data on gas and nitrogen metabolism in the organism. Indeed, in equation (4.3), the quantities of gram-molecules can now be defined as follows:

$$4{,}270\ C_{6{,}0}H_{10{,}13}O_{3{,}29}N_{0{,}264} + 28{,}276\ O_2 = 24{,}755\ CO_2 + \\ + 20{,}343\ H_2O + 0{,}485\ NH_2CONH_2 + 0{,}125\ \{O\} + 0{,}095 \times \\ \times\ C_{4{,}0}H_{6{,}63}O_{1{,}44}N_{1{,}66}, \qquad (4.4)$$

from which we find that $\overline{RQ}$ = 0.8704 ℓ CO_2/ℓ O_2 (or 1.204 g CO_2/g O_2). The values of other indicators of mass transfer (see Table 6) are also closest to those obtained from experimental coefficients (see Table 6 and Figure 49) and equation (4.2).

Now the value of C in equation (4.2) is defined as the overall product of protein metabolism, including urea, oxygen of phosphates and sulfates, as well as additional organic matter, with an overall composition of $C_{4.0}H_{6.63}O_{1.44}N_{1.66}$. The amount of such organic matter constituted a mean of 31% of urea output (from 29.1 g/day) and included about 14% of the nitrogen contained in urine (according to data with ECES).

Thus, these estimates show that one can calculate with adequate accuracy all of the parameters of equilibrated mass transfer associated with constant energy

transfer in the human body proceeding from gross biochemical and element composition of assimilated dietary organic matter and using, as equivalents or typical compounds, casein, triolein and starch. The results thus obtained conform well with experimental data, with consideration of the most important organic and oxygen-containing metabolites of protein metabolism. This is confirmed by comparison of experimental and estimated gas and water coefficients (see Table 6), obtained for the process of biological oxidation of the main constituents of food, as well as indicators of mass transfer calculated with equations (4.2) and (4.4) for the established level of Q_{man} (see Table 7).

Table 7. Estimated mean daily indicators of mass transfer in man with energy expenditure of 136 W, using diets with different biochemical composition

Intake				Output			$\overline{RQ}$, $\ell CO_2/\ell O_2$
total, g/day	assimilable g/day		ξ ratio	O_2	CO_2	H_2O	
				g (ℓ*)/day			
Protein 115.0	Protein	98.3					
Fats 44.8	Fat	42.3	5.34	901.1 (630.6)	1159.2 (586.4)	384	0.930
Carbohydr. 561.7	Carbohydr.	542.0					
Allowance 721.5	Allowance	682.6					
Protein 115.0	Protein	98.3					
Fat 106.2	Fat	100.4	1.67	904.5 (633.0)	1096.7 (554.8)	368	0.876
Carbohydr. 417.1	Carbohydr.	402.5					
Allowance 638.3	Allowance	601.2					
Protein 115.0	Protein	98.3					
Fat 113.2	Fat	107.0	1.50	904.8 (633.2)	1089.5 (551.1)	366	0.870
Carbohydr. 400.6	Carbohydr.	386.6					
Allowance 628.8	Allowance	591.9					
Protein 115.0	Protein	98.3					
Fat 142.3	Fat	134.5	0.99	906.4 (634.3)	1059.9 (536.2)	359	0.845
Carbohydr. 332.2	Carbohydr.	320.6					
Allowance 589.5	Allowance	553.4					
Protein 115.0	Protein	98.3					
Fat 169.7	Fat	160.4	0.67	907.9 (635.4)	1032.0 (522.1)	352	0.822
Carbohydr. 267.8	Carbohydr.	258.4					
Allowance 552.5	Allowance	517.1					
Protein 115.0	Protein	98.3					
Fat 192.8	Fat	182.2	0.47	909.2 (636.2)	1008.6 (510.2)	346	0.802
Carbohydr. 213.6	Carbohydr.	206.1					
Allowance 521.4	Allowance	486.6					
Protein 115.0	Protein	98.3					
Fat 245.2	Fat	231.7	0.16	912.0 (638.2)	955.3 (483.3)	333	0.757
Carbohydr. 90.5	Carbohydr.	87.3					
Allowance 450.7	Allowance	417.3					

Note: Urea output was the same in all considered cases--29.1 g/day--by virtue of the fact that the protein level q_F^{prot} in the assimilated allowances (14% for energy) and share of urea nitrogen in N_{tot} were considered to be constant.

The energy value of organic matter, which was determined from biochemical composition, enables us to determine the quantity thereof that is required to meet in full

man's energy expenditure. The energy value $\overline{\Delta q}$ of assimilable food can also be calculated with the structural formula for equivalents of protein, fat and carbohydrates on the basis of energy of dissociation of chemical bonds [138] and levels thereof in initial and end products of oxidation. In most cases, however, the approximate values of $\overline{\Delta q}$, determined from Figure 49, are adequate. Using these data for food allowances with different biochemical (and, accordingly, element) composition, as well as the stoichiometric correlations between substances constituting equations of type (4.4), we calculated the respiratory quotients, overall uptake and output of O_2, CO_2, H_2O and urea for Q_{man} = 136 W (Table 7). We used the above-mentioned coefficients of assimilation of different constituents of the allowance.

According to the figures listed in Table 6, CO_2 output is subject to the greatest changes upon oxidation of diets with different values for ξ. Consequently, regulation of $\overline{RQ}$ by altering the proportion of carbohydrates and fat in the diet will reflect primarily CO_2 content in the atmosphere of the life support system.

The obtained mass transfer values of the decisive unit, scaled per person, with a specified level of energy expenditure, constitute the result that enables us to go on to determination of corresponding characteristics of the algal culture that regenerates gas and water, and utilizes soluble metabolites (waste) in a system with the structure and variant described.

4.3. Corresponding Mass Transfer Characteristics of Microalgal Culture

In a BLSS, the culture of microalgae emerges as the metabolic counterweight for the "human" element, implementing regeneration of substances in the course of biosynthesis, on the basis of absorbed radiant energy. As we know, the direction of plant photosynthesis is a natural compensator of the process of oxidation of organic compounds.

With reference to algae as the chief biological component of the regenerative unit of the system, we must first of all determine the stoichiometric correlations, in which different substances are taken in and put out in the course of biosynthesis, and thereby form a balance equation analogous in appearance to (4.4), but opposite in direction of conversions. This direction is attributable to the process of storing potential energy in the synthesized organic substance due to energy of photosynthesis-activating radiation and by means of cell photosynthesis. The initial compounds for this process in the system will consist of products of oxidation of the food allowance in the human body. One of the first and foremost objectives of studies of algal cultures in this aspect is to coordinate mass transfer parameters and characteristics of both elements of the BLSS in order to assure equiponderant conditions for different substances.

Special mention must be made of the fact that, in the case of equiponderant gas exchange in a BLSS, it is only through biosynthesis of algae that there can be simultaneously complete utilization of both urea and other end products of oxidation of the overall organic matter in the food allowance. Calculation of the productivity of algae under these conditions requires addition to the culture of extra (in relation to utilized urine) amounts of biogenic elements N, P, K, Mg, S and Fe, in order to obtain the physiologically normal biochemical composition of cells. Retention of such a composition of algae during cultivation yields the maximum growth rate and productivity for O_2, uptake of CO_2, H_2O and formation of

biomass, and thereby allows us to obtain a more efficient regeneration process, with regard to both energy and technology. Hereafter, we shall discuss expressly such a variant of BLSS, with a culture of different species of microalgae as the sole regenerator of gas and water.

There may be different tasks for the algal part of the system, for example when a cell culture implements only partially the exchange of gases and atmosphere regeneration, but makes complete use of biogenous waste from other units and, concurrently, effects complete or partial exchange of water. The amounts of N, K and Na contained in liquid excreta of man can also determine the required level of productivity (for O_2) of algae in a BLSS. Some of these examples have been obtained in experiments with ECES (see Table 3 and footnote to it).

In the course of algal photobiosynthesis, the organic matter of cells is synthesized with delivery to them of CO_2, H_2O and minerals from the culture medium. Macroelements N, P and S, including Fe, pass into cells mainly with oxygen-containing compounds. Nitrates, urea, ammonia and diverse mixtures are common sources of nitrogen for algal cultures. Each form of nitrogen has its own assimilation quotient (AQ) for the culture of algae, which is the ratio of CO_2 uptake to output of photosynthetic O_2. As an integral indicator, AQ includes the end correlations between exchanged gases, which are established during stationary processes of photosynthesis and respiration of cells. In this case, AQ corresponds to RQ, as for exchange of gases in the opposite direction (ultimately). Aside from the form of nitrogen, the value of AQ is affected also by the overall biochemical (and, consequently, element) composition of biomass synthesized by algae. In order to determine with the balance equation the specific utilization of different substances involved in cell biosynthesis, we must have results that conform well with respect to element composition of biomass, source of nitrogen, etc. Such data were obtained in one of the experiments with ECES lasting 90 days.

The composition of biomass and corresponding indicators of gas and nitrogen metabolism of a culture of Chlorella vulgaris used in an experiment with a "man--microalgae--higher plants--microbial culture" ECES [130] was as follows:

Experiment No (according to Table 3)		3
Composition of organic matter in biomass, %:	crude protein	59.25
	lipids	28.27
	all types of carbohydrates	12.5
Overall element formula AQ:		$C_6H_{9.7}O_{2.635}N_{0.927}$
	ℓ CO_2/ℓ O_2	0.874
	g CO_2/g O_2	1.209
Source of nitrogen		NH_2CONH_2

Note: The composition of biomass organic matter is given as a percentage (without minerals P, K, S, Mg, Na, Fe and others). However, dry algal biomass contains both organic matter and minerals, which constituted a total of 3.8%.

We can formulate the following equation from the results submitted above and the experimental conditions:

$$12{,}390\ CO_2 + 8{,}779\ H_2O + 1{,}037\ NH_2CONH_2 + 0{,}445\ \{O\} = \\ = 14{,}572\ O_2 + 2{,}238\ C_{6,0}H_{9,70}O_{2,035}N_{0,927}, \qquad (4.5)$$

from which we have $\overline{AQ}$ = 0.845 ℓ CO_2/ℓ O_2, versus 0.874 according to experimental measurement of gas exchange. The amount of oxygen entering cells with phosphorus (scaled to P_2O_5) and sulfur (SO_3) totaled 24.6% of the nitrogen in dry biomass of algae. The mean productivity of the chlorella culture, with respect to total synthesized organic matter constituted 306.6 g/day in this experiment. According to equation (4.5), in relation to this matter photosynthetic oxygen constitutes 1.064 ℓ* O_2/g or 1.521 g O_2/g, carbon dioxide uptake is 0.900 ℓ* CO_2/g, or 1.779 g CO_2/g and photolysis water is 0.516 g H_2O/g.

In the general case, the organic matter of algae is contained both in whole cells and fragments thereof, and in dissolved metabolites which are constantly present in the pericellular (background) environment. Ultimately, photosynthetic products are the source of this matter, which serve either as the structural basis or supplier of energy for synthesis. For this reason, an equation of the (4.5) type includes overall organic matter generated as a whole by the algobacterial cenosis that is formed in the culture (this was determined from the results of the 90-day experiment with ECES). However, with the intensive cultivation of algae, the contribution of concomitant microflora to overall productivity of the culture is often relatively small.

Equation (4.5) does not take into consideration other organic compounds, which are also present in liquid human excreta utilized by chlorella. This is attributable to the fact that they contain no more than 2.2% of the total nitrogen required by the algal culture, in which 24 to 30% of the nitrogen is presently represented by ammonia that is added from the system's supply.

A more significant circumstance turned out to be that urea is decomposed after addition to the culture medium. After only a few hours of cultivating algae, when medium with human metabolites is used many times, urease activity of the cells' background environment reached such a level that the urea passing into the culture (under the experimental conditions) broke down before it was utilized. Utilization of nitrogen by algae then proceeds in the form of protonated ammonia, while ammonia appears as a result of the following reaction:

$$H_2CONH_2 + H_2O \xrightarrow[\text{(urease)}]{} 2NH_3 + CO_2.$$

At pH of 7.0-7.5 (which is typical for chlorella cultures), up to 99% of the ammonia in the background medium is represented in the form of NH_4^+.

If we consider that urea, which is completely decomposed in the medium, is the source of nitrogen in the form of NH_4^+, as before, for photosynthesizing cells, the value of $\overline{AQ}$ determined with equation (4.5) is 0.876 ℓ CO_2/ℓ O_2 (1.213 g CO_2/g O_2). A comparison of the cited values of $\overline{AQ}$ shows that a significant part (about 92%) of the urea utilized by chlorella in reality in the above-mentioned experiment is in the form of end products of its decomposition, i.e., NH_4^+ and CO_2.

We obtain the following values for mass transfer coefficients for the element (and biochemical) composition of chlorella used in our estimates with substitution of

urea nitrogen with nitrate (HNO_3) in equation (4.5): $\overline{AQ}$ = 0.713 ℓ CO_2/ℓ O_2 (0.986 g CO_2/g O_2), 1.368 ℓ* O_2 (1.954 g O_2/g) and 0.577 g H_2O/g. It must also be stated that overall biochemical composition of chlorella cells cultivated with nitrates differs somewhat from the one used in the described calculations.

Let us now consider another means of supplying nitrogen for the culture, when cells used a mixture of forms, NH_4NO_3. For this source, other conditions remaining unchanged, we have: $\overline{AQ}$ = 0.802 ℓ CO_2/ℓ O_2 (1.109 g CO_2/g O_2), 1.738 g O_2/g and 0.516 g H_2O/g organic matter.

We must call attention to the fact that for the nitrogen source--urea, containing one atom of C per two atoms of N, the specific uptake of CO_2 by algae is the same for all conditions of nitrogen nutrition of cells based on urea. For other sources of nitrogen, if they are the only ones, the uptake of CO_2 is different, but it is also constant when the element composition of algae is unchanged.

A promising means of nitrogen nutrition of algae for BLSS is based on the use of urine urea (in the form of NH_4^+ and CO_2), along with an additional amount of nitrogen in the form of NH_4NO_3. Ye. K. Lebedeva and G. I. Meleshko [139] have indicated that, in such a case, algae can utilize nitrate and ammonia nitrogen simultaneously.

In view of the fact that urine urea constitutes a mean of 30% of the amount required by a chlorella culture that implements equiponderant gas exchange in a two-component BLSS, it is easy to determine the corresponding mass transfer parameters: $\overline{AQ}$ = 0.822 ℓ CO_2/ℓ O_2 (1.137 g CO_2/g O_2), 1.656 g O_2/g, 1.883 g CO_2/g and 0.479 g H_2O/g organic matter. The obtained assimilation coefficient of the culture is close to the value of $\overline{RQ}$ obtained for a mixed diet [128]. Diets with $\overline{RQ}$ in the range of 0.82-0.85 are typical for space flights [140].

This analysis makes it possible to select the values of the main parameters and characteristics of a microalgal culture, which would provide for the gas (and concurrently water) requirements of man in a BLSS with a fixed Q_{man}. Table 8 lists the results of estimating mass transfer and productivity of chlorella culture for organic matter and dry biomass (g absolutely dry substance) when using different sources of nitrogen in cell nutrition. The main condition was met, i.e., obtaining an equiponderant exchange of gases in a two-component system. The values of ξ are also listed for human dietary allowances that make it possible to meet this condition with respect to the assimilation quotient: $\overline{RQ}$ = $\overline{AQ}$.

According to the data in Table 8, if urea is used as the sole source of nitrogen for cells, $\overline{AQ}$ may vary from 0.876 to 0.845 ℓ CO_2/ℓ O_2, depending on degree of dissociation in the culture medium. When $\overline{RQ}$ is coordinated (by means of the ξ ratio) with the changing assimilation quotient, productivity (P) of the culture will decrease from 640.7 to 619.2 g (dry biomass)/day. This decline is attributable to diminished amounts of CO_2 passing from man to algae. CO_2 delivery to cells in an ECES usually emerges as a factor that limits growth, by means of which there can be self-regulation of culture productivity and CO_2 content in the system's atmosphere when there is a direct gas link between elements.

The degree of dissociation of urea in the medium and, consequently, change in $\overline{AQ}$ can be regulated by altering the frequency and volume of urea added to the culture. The degree of dissociation will vary, depending on the time urea spends in the medium before uptake by algae, and this permits regulation of this process.

Table 8. Parameters of productivity of Chlorella vulgaris culture providing for equiponderant gas exchange in BLSS (Q_{man} = 136 W) as related to different sources of nitrogn

Assimil. quotient $\overline{AQ}$, ℓ CO_2/ℓ O_2	Uptake: N-subst., uptake condit. g/day	Uptake: H_2O	Uptake: CO_2 total, g/day	Uptake: CO_2 specific, ℓ*/g (dry biomass)	Output: O_2, g/day	Output: Productivity organic matter, g/day	Output: Productivity dry biomass g/day
0,930	NH_2CONH_2 – 33,9, utilized in form of $(2NH_4^+ + CO_2)$; NH_4^+ – 54,6	242	1159,2	0,919	901,1	614,3	638,3
0,876	NH_2CONH_2 – 125,3, util. in form of $(2NH_4^+ + CO_2)$	243	1096,7	0,866	904,5	616,5	640,7
0,870	NH_2CONH_2 – 124,4, 80% – util. in form of $(2NH_4^+ + CO_2)$	256	1089,1	0,866	904,9	612,3	636,3
0,845	NH_2CONH_2 – 121,1, utilized without breakdown in medium	307	1039,9	0,866	906,4	595,9	619,2
0,822	NH_2CONH_2 – 33,4, util. in form of $(2NH_4^+ + CO_2)$; NH_4NO_3 – 103,9	263	1032,9	0,917	907,9	548,1	569,6
0,802	NH_4NO_3 – 141,7	270	1008,6	0,938	909,2	523,2	543,7
0,757	NH_2CONH_2 – 34,1, util. in form of $(2NH_4^+ + CO_2)$; HNO_3 – 145,3	263	955,3	0,914	912,0	508,6	528,5

Note: The biochemical composition of algae is considered the same for the indicated conditions of nitrogen nutrition for cells.

Productivity of 640.7 g (dry biomass)/day) of the chlorella culture is the maximum (P_{max}) when using urea for nitrogen nutrition of cells, and it can be taken as the level that is entirely determined by the light provided for algae in culture.

Any decline of productivity (starting with P_{max}) due to limitation by carbon dioxide caused by change in $\overline{RQ}$ would require appropriate changes in nitrogen nutrition of algae in order to obtain O_2 equilibrium in the closed system. But the nature of actual regulation of culture productivity will remain the same as for changing concentrations of CO_2 in the stream of air flowing through the layer of the cell suspension [68].

In order to assess the energy of a photosynthesizing chlorella culture that would meet the gas requirements of man in a two-component BLSS with specified Q_{man}, we are justified in basing ourselves on the value of P_{max}, which is determined by the intensity of PAR [photosynthesis activating radiation] influencing the algae. Thus, actual productivity will be somewhat lower than P_{max} due to addition of CO_2, which limits cell growth, as the simplest means of providing stable gas equilibrium in the system. This also adds a certain spare productivity, which is needed to regulate the regeneration process when there is a direct gas link between components.

The values of P_{max} obtained for other species of algae representing different systematic groups (Table 9) are referable to the same conditions of nitrogen nutrition of cells as for chlorella, as being the most suitable (according to $\overline{AQ}$) in a BLSS. We refer to the use of the ammonia form of nitrogen, which appears in the culture medium after decomposition of urea in it. We took into consideration the chemical composition of different species, which differs from that of Chlorella vulgaris. There are details about the composition of biomass of Spirulina platensis, Synechococcus elongatus (Cyanophyta) and Platymonas viridis (Chlorophyta) microalgae in the works of I. N. Trubachev et al. [86] and I. V. Gribovskaya et al. [141]. The results of the cited works were used to calculate the corresponding element formulas and then, using equations of the (4.5) type, calculation was made of the mass transfer characteristics of cultures of different algae (see Table 9). The element composition of algal protein was determined from the sum of amino acids with adjustment of H and O content according to control estimates for casein.

Table 9. Maximum productivity, P_{max}, of cultures of different species of algae corresponding to equilibrated gas exchange in the BLSS (Q_{man} = 136 W) with utilization by cells of a carbon dioxide source of carbon and ammonia form of nitrogen in the medium

Species	$\overline{AQ}$ & CO_2/& O_2 (ξ ratio)	Uptake				Output		
		CO_2		H_2O, g/day	N= substances, utilization conditions, g/day	O_2, g/day	P_{max}	
		total, g/day	specif. &*/g (dry biomass)				organ. matter	dry biomass, g/day
Spirulina platensis	0,799 (ξ=0,45)	1005	0,894	272	NH_2CONH_2 — 107,2, utilized in form of $(2NH_4^+ + CO_2)$	909,4	525,8	568,9
»	0,843 (ξ=0,95)	1056,8	0,943	271,2	NH_2CONH_2 — 32,1, util. in form of $(2NH_4^+ + CO_2)$; NH_4^+ — 44,9 (in addition to urea)	906,6	524,2	567,1
Synechococcus elongatus	0,814 (ξ=0,59)	1023,5	0,904	257,1	NH_2CONH_2 — 120,1, util. in form of $(2NH_4^+ + CO_2)$	908,3	551,0	572,6
Platymonas viridis	0,771 (ξ=0,24)	972	0,793	301,4	NH_2CONH_2 — 87,2, util. in form of $(2NH_4^+ + CO_2)$	911,1	498,7	620,3

Overall formulas were obtained for algal organic matter: $C_{6.0}H_{10.84}O_{2.06}N_{0.87}$ (Sp. platensis), $C_{6.0}H_{10.58}O_{2.18}N_{0.95}$ (S. elongatus) and $C_{6.0}H_{11.49}O_{2.07}N_{0.74}$ (Pl. viridis).

The biochemical composition of these species was examined with nitrate as nutrition for the algae. In determining P_{max} it was assumed that this composition would not change appreciably if there was a change to urea, a nitrogen source that breaks down in the culture medium, i.e., to the NH_4^+ form for the cells.

Two similar values for productivity are listed in Table 9 for the culture of Sp. platensis blue-green algae, but with an appreciable difference in $\overline{AQ}$. Thus, if

30% of the nitrogen utilized by this culture is added in the form of urea, which breaks down completely in a medium with end products of NH_4^+ and CO_2, and 70% of the nitrogen has additional amounts of NH_4^+, the value of $\overline{AQ}$ will increase to 0.843 ℓ CO_2/ℓ O_2 (CO_2 carbon source). This is virtually the highest $\overline{AQ}$ reached for this algae with consideration of BLSS conditions. Productivity of the culture is close to P_{max} (see Table 9).

Using the previously known caloric value ($\overline{\Delta h}$) of biomass from different species (see Chapter 1), one can determine from P_{max} the overall amount of energy stored by algae in the course of photosynthesis (Q_{alg}) (Table 10).

Table 10. Energy parameters of different algal species

Species	Caloric value of biomass, $\overline{\Delta h}$, kJ/g	Stored energy $\frac{P_{max}}{Q_{alg}}$, W	Concordance of energy transfer between units, $\eta_Q = \frac{Q_{man}}{Q_{alg}}$, %
Chlorella vulgaris	22.48	166.7	81.5
Spirulina platensis	20.75	136.7	99.5
Synechococcus elongatus	21.35	141.5	96.1
Platymonas viridis	19.85	142.6	95.4

The energy stored by algae in the course of photosynthesis is higher for all species (though insignificantly in some instances), than the corresponding energy expenditure by man in a closed system that is gas-equilibrated, as can be seen from Table 10. This is attributable to differences in biochemistry of organic food matter and cell biomass. But, because of the nitrogen source, it becomes possible to have conformity between assimilation coefficient $\overline{AQ}$ and respiratory quotient $\overline{RQ}$ within the permissible range of changes in the latter.

The obtained results concerning Pmax productivity and stored energy for cultures of different algae enable us to turn to determination of their photoenergetic parameters for the BLSS variant under study.

4.4. Photoenergetic Parameters of Algal Culture in the System

One can determine the amount of radiant energy of PAR [photosynthesis activating radiation] absorbed by the culture, Q_{abs}^{PAR}, from the found mean daily values for energy stored by algae, Q_{alg}, contained in the growing biomass (in P_{max}), if the energy efficiency of photobiosynthesis, η_{pb} of cells in a BLSS is known. Indeed, according to the equation for η_{pb} (see equation (1.1)), one can calculate absorbed PAR energy with the following equation:

$$Q_{abs}^{PAR} = Q_{alg}/\eta_{pb} \qquad (4.6)$$

using the values of Q_{alg} listed in Table 10. Then it is not difficult to determine the minimal amount of radiant energy (Q_{min}^{PAR}) absorbed by the culture per day, corresponding to maximum efficiency (η_{pb}^{max}), for example, under the effect of continuous flux of PAR. In this case, η_{pb} constitutes the following values: 0.130 for Chl.

vulgaris, 0.132 for S. elongatus, 0.175 for Pl. viridis and 0.135 for Sp. platensis (see Chapter 1). The values of (Q_{min}^{PAR}) obtained on this basis correspond to power in the range of 815 to 1282 W for cultures of different species of algae that effect equilibrated gas transfer in a BLSS with Q_{man} = 136 W. Hence, absorption of 77.2 to 122.5 kJ radiant energy in the PAR range is required to produce 1 g O_2 by means of a culture of microalgae. This is equivalent to outlay of 24.4 to 34 W radiant energy to obtain 1 g photosynthetic O_2 per hour, or 30.6 to 48.6 W per ℓ* O_2/h.

We can find an approximate estimate of energy consumption of physicochemical LSS in some works dealing with life support systems for man [115, 127]: about 1 kW electric energy per person. Energy uptake by a culture of microalgae is on the same level when it regenerates substances in a BLSS, but then it is in the form of PAR radiant energy. Thus, the energy-related advantage of using algae for regeneration purposes depends entirely on the type of energy source. If it is solar radiation, the advantage of a photosynthesizing cell culture is obvious, since in this case the radiant energy from an external source is used "directly" by means of photobiosynthesis for production of O_2 and absorption of CO_2 in the system, in the acceptable amounts, and it does not have to be transformed to a great extent into some other form for the above purposes. At the same time, for physicochemical LSS, radiant energy must first be transformed, for example, with solar batteries (involving considerable loss), so that it can then be used in the same amounts, in the form of electric power, in the regeneration process. The situation changes to the opposite if the energy source is internal (for spacecraft and space stations) and energy is supplied in the form of electricity. Thus, if artificial light sources--lamps--are used exclusively in the algal component, the electricity they consume would be:

$$\overline{Q}_{el} = Q_{abs}^{PAR}/\eta_{el}^{PAR} \cdot \eta_{il} \qquad (4.7)$$

where η_{el}^{PAR} is energy efficiency of the lamps which indicates the share of PAR energy in total electricity used by the lamps, η_{il} is illumination efficiency of the cultivation device, which is the ratio of PAR absorbed by the culture to total radiant power of the lamps ($\overline{Q}_{lam}^{PAR}$).

In order to find the most important parameter of the algae unit, effective light-receiving surface (S_0) of the photosynthesizing culture, we use the formula:

$$S_0 = Q_{abs}^{PAR}/E_0 \text{ (for suspension layers with total absorption)} \qquad (4.8)$$

If gas is passed through the suspension of cells during cultivation, the formed air bubbles lower "capture" of radiant flux to the culture. In this case the surface of effective light reception of the culture, with adjustment for volume, occupied by gas bubbles is determined by the following equation:

$$S_0 = i \cdot S \qquad (4.9)$$

where coefficient $i<1$ and S is the area of the light-receiving surface of the reactors (equipment).

With the use of artificial light sources powered by electricity, the overall energy efficiency (L) of the algae cultivator, which constitutes:

$$L = \eta_{pb} \cdot \eta_{el}^{PAR} \cdot \eta_{il}, \qquad (4.10)$$

is usually low, constituting about 1-2%. For this reason, the overall power of the light sources could reach significant levels (7.5-20 kW).

Knowing function $\eta_{pb} = \eta(E_0)$ and the values of Q_{abs}, η_{el}^{PAR}, η_{il}, it is easy to find the mean daily energy (power) $\bar{Q}_{el}$, area of efficient function of surface S_0 of the algal suspension and overall power of the lamps, $\bar{Q}_{lam}^{PAR}$, as a function of illumination of the culture of microalgae, using formulas (4.6)-(4.8). Figure 51 illustrates these values as a function of illumination E_0 with Q_{alg} = 146 W, η_{el}^{PAR} = 0.163, η_{il} = 1 and efficiency of algal photobiosynthesis $\eta_0^0 = \eta(E_0)$, which were determined experimentally and illustrated in Figure 21 [not reproduced]. Evidently, with η_{il} 1 the overall power of the lamps increases by $1/\eta_{il}$ times.

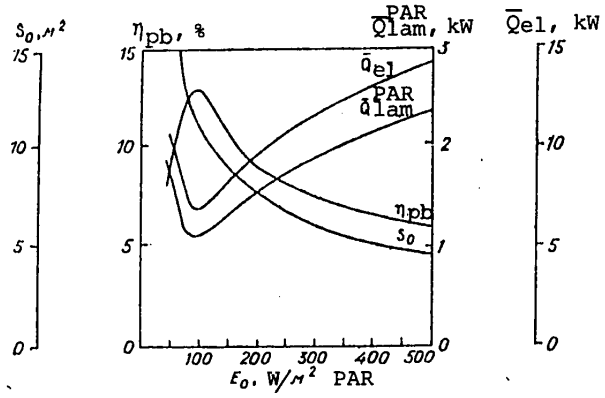


Figure 51. Overall electric power of lamps ($\bar{Q}_{el}$), their total radiant energy in the PAR range ($\bar{Q}_{lam}^{PAR}$), energy efficiency of algal photobiosynthesis (η_{pb}) and area of effective light-receiving surface of the culture (S_0) as a function of illumination (E_0) with η_{il} = 1

According to Figure 51 and equations (4.6)-(4.10), maximum efficiency of the microalgal component is achieved with illumination that provides for maximum efficiency, η_{pb}^{max}, but then the area of the working surface of the reactors is of a considerable size.

In developing and designing an experimental installation that has to provide for the oxygen requirements of one man in an ECES, our aim was to have a relatively small cultivator for the algae, with high reliability, that would be simple to operate and control the regeneration process, which would enable us to cultivate chlorella with relatively high photobiosynthetic efficiency. The cultivator reactors created for these purposes consisted of plane-parallel cuvettes with a total light-receiving surface S = 8-10 m^2 and layer thickness of about 0.5 cm. The cuvettes were illuminated on two sides with DKsTV-6000 xenon lamps. The presence of strong xenon lamps enabled us to vary the illumination of the culture from 60 to 360 W/m^2 PAR and, accordingly, to alter its productivity.

The working volume of suspension (V_w) and optimum volume of algal biomass in it (G'_{opt}) during cultivation in such cuvettes under bilateral light were determined with the following equations:

$$V_p = 0.5\ x\ S_0 \tag{4.11}$$

$$G'_{opt} = G/0.5\ x \tag{4.12}$$

where $G_0 = G(E_0)$ was determined with equation (1.28)(illustrated in Figure 22). In the case of unilateral illumination V_p increases while G_{opt} decreases to one-half the indicated value. In equation (4.11), x is the thickness of suspension layer.

In a functioning cultivator, the relative volume taken up by gas bubbles constituted 0.15. With consideration of this adjustment, the effective light-receiving surface of the cuvettes constituted $S_0 = 6.8\ m^2$ (for $S = 8\ m^2$), while the working volume of the culutre, V_p constituted 17 ℓ (bilateral illumination of the trays).

The algal cultivator for an ECES has essentially the same units and systems as the experimental installation (see Fiugre 1), but the parameters of its elements were calculated in accordance with the specified productivity of the cultivator, which was required to effect closed and equiponderant transfer of gases in the system.

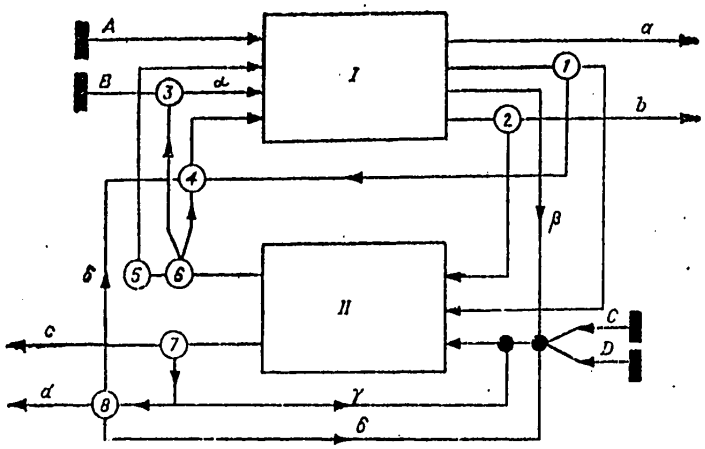


Figure 52. Diagram of experimental "man-microalgae" closed ecosystem

I) heterotrophic component of system (man in pressure chamber)
II) photoautotrophic component (algobacterial culture)
1) cabin condensate unit
2) liquid waste unit
3) food liquid unit
4) sanitation and housekeeping water
5) carbon filter for air
6) algae cultivator condensate unit
7) centrifuge for suspension of cells
8) vacuum distillation of suspension centrifugate
A) air-dried foodstuffs (for man)
B) salt supplement to intrasystem food water
C) biogenous substances for microalgae
D) extrasystem distilled water to compensate for removal from system
a) solid human excreta
b) residue after filtering liquid waste
c) wet algal biomass
d) residue after vacuum distillation of suspension centrifugate
α) drinking water
β) liquid human excreta
γ) suspension centrifugate
δ) vacuum distillate of centrifugate
—) movement of gas flux
—) flow of liquids and other substances
Circles--flow-mixing sites
Squares--stock [reserves]

In addition to the algae cultivator, a two-component ECES has a pressure cabin, as well as units that permit gas and water exchange between the heterotrophic and phototrophic components, monitoring and control of processes occurring in the different components.

Without dwelling in detail on the design and operating characteristics of different units and elements of the experimental two-component biotechnological system, we shall merely indicate its general scheme of function. The system consists of the following components: heterotrophic (man in the pressure chamber) and photoautotrophic (algal and bacterial culture). Figure 52 illustrates the operating principle of the system and directions of flow of the main substances--gas, nutrient media and other components.

Testing revealed that the productivity of the algae cultivator conforms with the estimated data and meets well man's oxygen, water requirements, and provides for utilization of carbon dioxide and a significant part of other products of man's vital functions.

In all of these experiments, the productivity of the algal component was limited by the carbon dioxide content in the air bubbles from the pressure chamber. Man's O_2 uptake and CO_2 output were determined by the degree of energy transfer activity. In the daytime, there was some accumulation of carbon dioxide in the system and increase in productivity of algae; at night, there was a decrease in this gas and in productivity of the algal culture.

Thus, the two-component "man--microalgae" system is a self-regulating and self-stabilizing system, in which man is not only the consumer but object that provides for the required regenerating activity of the microalgal component, i.e., the productivity of the latter is determined entirely by the degree of man's gas exchange activity. This is achieved by limiting productivity with carbon dioxide, when there is a direct gas link between the components. At the same time, in the presence of limiting concentrations of CO_2 in bubbled air, the energy efficiency of algal photobiosynthesis diminishes. However, it can be improved by means of automatic reduction of illumination to the levels required for the appropriate productivity of the cultivator.

10,657
CSO: 1840/999

ENVIRONMENT

UDC: 591.9

CURRENT PROBLEMS OF ZOOGEOGRAPHY

Moscow SOVREMENNYYE PROBLEMY ZOOGEOGRAFII in Russian 1980 (signed to press 11 Nov 80) pp 2, 321-323

[Annotation and abstracts from book "Current Problems of Zoogeography", edited by A. G. Voronov, doctor of geographic sciences, and N. N. Drozdov, candidate of geographic sciences, Institute of Evolutionary Morphology and Ecology of Animals imeni A. N. Severtsov and Scientific Council for the Problem of "Biological Bases for Development, Reconstruction and Protection of the Animal Kingdom," USSR Academy of Sciences, Izdatel'stvo "Nauka", 2100 copies, 324 pages]

[Text] This collection contains articles on the main theoretical, methodological and practical problems of modern biogeography and zoogeography. The general section discusses the directions of development, prospects and general methodological approaches in the most recent biogeographic research. The section dealing with typology and regional distribution of fauna and the animal population, includes articles describing new special methods of zoogeographic mapping and methodological procedures in zoogeographic zoning. Original data are submitted on rodents and other small mammals, birds and insects. There is discussion of the structure of the fauna of Eurasia, the Paleotropics, and some narrower regions--Turanskaya Plain and Central Asia. In the section dealing with ecological geography of communities there are articles describing and discussing the communities in humid tropical forests and mountain forests of equatorial Africa. This collection gives us an idea about the directions of modern biogeography and zoogeography, the new methods and objects of research, as well as the practical implications of this discipline.

UDC: 591.9

SOME DIRECTIONS OF DEVELOPMENT OF CURRENT ZOOGEOGRAPHY

[Abstract of article by A. G. Voronov]

[Text] Information is given about the current status of biogeography, structure of biogeographic work and the main trends of development of this discipline.

UDC: 591.9

THE PROBLEM OF INVESTIGATIVE METHOD IN ZOOGEOGRAPHY

[Abstract of article by Ye. V. Rotshil'd]

[Text] This article is concerned with development of scientific methodology and a description of the method used, as well as evaluation of the hypothesis. References 10.

UDC: 591.9

APPROACHES AND METHODS OF MODERN SYNTHETIC BIOGEOGRAPHY

[Abstract of article by P. P. Vtorov]

[Text] This article defines the concepts and conceptions, current goals and tasks of biogeography, division of ecosystems into units, approaches to evaluation [bonitation] in the choice of standard sections of the biosphere. Tables 4, references 53.

UDC: 591.9

VOLUME AND ZOOGEOGRAPHIC SUBDIVISION OF THE PALEOTROPIC DOMINION

[Abstract of article by O. L. Kryzhanovskiy]

[Text] This article makes an attempt at revising the traditional volume [scope?] and separation of the paleotropic dominion. Madagascar and adjacent islands were singled out as an independent zoogeographic region. It is suggested that the Papua biogeographic region be included in the paleotropic dominion. Figures 1, references 27.

UDC: 595.772

TYPING THE HORSEFLY FAUNA AND ZOOGEOGRAPHIC ZONING OF THE USSR

[Abstract of article by N. G. Olsuf'yev]

[Text] This article submits data from studies of the range of horseflies on the territory of the USSR. Tables 2, figures 12, references 15.

UDC: 591.9

GROUPING OF POPULATION OF SMALL MAMMALS AND THEIR TERRITORIAL DISTRIBUTION IN THE EASTERN HALF OF THE MONGOLIAN PEOPLE'S REPUBLIC

[Abstract of article by V. V. Kucheruk, N. V. Tupikova, B. P. Dobrokhotov, N. N. Lebedeva and P. M. Baranovskiy]

[Text] A total of 6828 pellets regurgitated by predatory birds containing the remainders of 10,214 small animals of 44 species were gathered in 142 sites. Analysis of this material established the composition of the fauna and dominant species. Thirteen groups of animal population were singled out on the basis of the

proportion of dominant species. Each group has a distinct geographic localization, and is related to specific vegetation, soil and topography. A map was charted of the location of groups of small mammal population. It was established that jerboas of the genera Salpingotus and Cardiocranius, which were believed to be extremely rare, are actually widespread and are the dominant small mammal in some types of deserts. Tables 4, figures 5, references 71.

UDC: 591.9

DISTRIBUTION AND TYPES OF RANGES OF JERBOA (DIPODIDAE, RODENTIA)

[Abstract of article by I. L. Kulik]

[Text] Reference cadaster maps have been plotted for the ranges of 25 jerboa species. Ten types of ranges were distinguished. The regions with a diversity of jerboa species coincide with the main centers of species-formation in the desert zone--Turanskiy and Mongolian ... [illegible portion] originate in Asian deserts, unlike gerbils which are of African origin. A comparative analysis of the ranges revealed that formation of the two main groups of desert rodents of the Old World--gerbils and jerboas--and their contemporary distribution are referable to different territories, which coincide only in part. Figures 9, references 67.

UDC: 591.9

MAPPING THE RANGE OF THE GREAT GERBIL IN CENTRAL ASIA AND KAZAKHSTAN BY THE METHOD OF DEGREE FIELDS

[Abstract of article by Yu. A. Dubrovskiy, A. S. Burdelov, I. V. Zhernovov, A. N. Korinfskiy, O. V. Mitropol'skiy and L. P. Rapoport]

[Text] The map of the range of the great gerbil, Rhombomys opimus Licht. in the Turanskaya Plain(in the USSR) was charted by designating the presence or absence of the species in different boxes, 1/24th the size of a trapezium graduated in degrees (10' longitude and 15' latitude) or 18×18--22 km. The method of degree fields makes it possible to illustrate graphically the distribution of the species within the range. Use thereof revealed that within the Turanskaya part of the range, great gerbils are present in virtually all boxes of this size. However, the borders of the range are not accurately depicted: in the case of 18×18--22 km boxes, the boundary may be 13-17 km wider than in actuality. For this reason, the map shows small settlements that are larger than the real ones, which are isolated from the main block of the range and are not demonstrable in territories unpopulated by this species, with a cross section of up to 30 km, situated within major dense settlements. Consequently, the method of degree fields does not permit reliable enough demonstration of intervals between settlements of the species, and it is unsuitable for comprehensive studies of spatial structure of their range. Conversely, with linear outlining of settlements, i.e., the range method, the main distinctions of the spatial structure of the species population are demonstrable quite accurately. There is also discussion of new data on the distribution of the great gerbil in the southern and northern parts of the range in the Turanskaya plain. Figures 1, references 42.

UDC: 598.2

CARTOGRAPHIC ANALYSIS OF STRUCTURE OF THE RANGE OF BIRDS OF OPEN LANDFORMS (ON THE EXAMPLE OF THE BLACK LARK IN NORTHERN KAZAKHSTAN AND PLAIN REGION OF ALTAYSKIY KRAY)

[Abstract of article by A. K. Danilenko]

[Text] A method was developed for plotting zoogeographic maps of the ranges of the black lark. When using it, one must take into consideration the specifics of different species in their habitats and the main biological features of the species. Tables 7, figures 14, references 79.

UDC: 598.2

SOME FAUNISTIC GROUPS OF BIRDS IN THE EURASIAN TAYGA

[Abstract of article by V. V. Brunov]

[Text] North-central, southern tayga and southern tayga-nontayga ornithofaunistic groups were isolated and studied comprehensively on the basis of analysis of range optimums and other biological distinctions of birds in the Eurasian tayga. It was proven that there are greater differences between the ornithofauna of north-central tayga and southern tayga forests than between the ornithofauna of the southern tagya and nontayga forests. The hypothesis is expounded that there are two independent groups of birds in the southern tundra and forest-tundra--overland and swamp-water groups. Hypotheses were also expounded concerning the conditions of formation of the tayga and southern tundra--forest tundra faunistic groups. Bird species were singled out that have range optimums in the subalpine field of Eurasian mountains. Figures 16, references 55.

UDC: 599.32

ZOOGEOGRAPHIC ANALYSIS OF THE RODENT FAUNA OF AFGHANISTAN

[Abstract of article by V. M. Neronov and L. P. Arsen'yeva]

[Text] A complex analysis was made of the distribution of 36 species of rodents of Afghanistan. It revealed that the territory of Afghanistan is not a zoogeographic entity, but consists of at least eight provinces and five "superprovinces." This is the first chart proposed for Afghanistan. Tables 3, figures 4, references 26.

UDC: 591.9

INTERPENETRATION OF FAUNISTIC COMPLEXES OF MAMMALS

[Abstract of article by I. L. Kulik]

[Text] There is a graphic chart of territorial correlations between mammals distributed in forest regions of the Palearctic Zone, which makes it possible to evaluate quantitatively the degree of penetration of species of different faunistic complexes into adjacent regions. The latitude range of 207 mammalian species was

demonstrated schematically. Groups of species were singled out that were characterized by a different types of distribution (faunistic complexes corresponding to different regions and groups of species distributed in several regions at a time). Analysis was made of quantitative proportion of different elements in the fauna of Palearctic forest regions. Tables 1, figures 1, references 27.

UDC: 599

ANIMALS AS COMPONENTS OF ECOSYSTEMS OF HUMID TROPICAL FORESTS

[Abstract of article by A. G. Voronov]

[Text] The important distinctions of humid tropical forests are described and distinctive features of the animal population defined. References 14.

UDC: 591.9

ANALYSIS OF MICROARTHROPOD COMMUNITIES IN MOUNTAIN FORESTS OF EQUATORIAL AFRICA

[Abstract of article by P. P. Vtorov, N. N. Drozdov, Ye. F. Martynova and V. G. Chelnokov]

[Text] A study was made of group composition, population size and biomass of microarthropods, as well as species composition of apterygotes collected with a standard "thermoeclector" [?], in tropical mountain forests near Lake Kivu (Zaire). Samples were taken from the top soil layer of 0-5 cm and under epiphytes. Substantial differences were demonstrated between communities in the epiphytic hanging soil layer and those from real soil. The general profusion and diversity of microarthropods are similar to the humid regions of temperate latitudes. A total of 26 species of Collembula, 3 species of Prothura and 1 species of Thysanura were found in 5 habitats (3 of which are epiphytic). Distinctive species compositions are formed in each of them, differing in both assortment of species and degree of their dominance in apterygotic communities. Both the species and generic composition of the studied complexes of apterygots differ substantially from the corresponding data for other regions of tropical Africa. Tables 5, references 11.

10,657
CSO: 1840/198

UDC: 517.9:577.4:575

DIVERSITY FACTORS IN MATHEMATICAL ECOLOGY AND POPULATION GENETICS

Pushchino FAKTORY RAZNOOBRAZIYA V MATEMATICHESKOY EKOLOGII I POPULYATSIONNOY GENETIKE in Russian 1980 (signed to press 11 Sep 80) pp 2-5, 196

[Annotation, foreword by A. M. Molchanov, doctor of physical and mathematical sciences, and A. D. Bazykin, candidate of physical and mathematical sciences, and table of contents from book "Diversity Factors in Mathematical Ecology and Population Genetics", edited by A. M. Molchanov and A. D. Bazykin, Soviet Committee for the "Man and Biosphere" Program of UNESCO, Working Group for Mathematical Modeling and Systems Analysis, Biological Research Center and Scientific Research Computer Center, USSR Academy of Sciences, Izdatel'stvo-Nauchnyy tsentr biologicheskikh issledovaniy AN SSSR v Pushchine, 500 copies, 196 pages]

[Text] This collection deals essentially with work in the field of analytical modeling in ecology and population genetics. Special attention is given to analysis of factors responsible for appearance and persistence of all sorts of types of diversity in ecosystems. The articles in this collection are divided into three groups, in accordance with the nature of the diversity analyzed: diversity of dynamic modes in model ecosystems, genetic diversity, special heterogeneity of ecological and population genetics systems. This collection is of interest to ecologists, geneticists, specialists in theory of biological evolution and in mathematical modeling in biology.

Foreword

The constantly increasing influence of human endeavor on the biosphere has resulted in irreversible changes in many natural systems in the last decades. In most cases, these changes lead, in turn, to serious adverse consequences to the economy and man's welfare in general. In recent times, forecasting the results of man's influences on natural ecosystems and prevention of adverse consequences has grown into a major general scientific problem, which is the concern of the largest national and international scientific organizations. The work that is being pursued in different countries within the framework of the "Man and the Biosphere" (MAB) UNESCO program is making a substantial contribution to the solution of this problem. Research in the field of mathematical ecology and mathematical population genetics is an important aspect of this work.

At the present time, this research is developing in two closely related but independent directions. The first type of work has as its goal computer description of processes occurring in some specific ecosystems and forecasting the consequences of influences on these ecosystems (portrait or simulation models). These models must usually be constructed from scratch for every natural object. Work in the

second direction is concerned with the study of situations that are simplified to the utmost degree and its purpose is not so much to describe specific natural systems as to demonstrate the most common, universal patterns as the basis of function and structuring of such systems (analytical models). The practice of opposing these approaches (which prevailed in the recent past) is being overcome more and more, and replaced with wise combination thereof. Many experiments, that are impossible under natural conditions (since they could lead to destruction of the system studied) can be well replaced with a digital experiment on a simulation model. On the other hand, the immensity of simulation models is alleviated appreciably by the fact that their behavior can usually be described with simple analytical models under the most interesting and important extreme conditions.

This collection, which was prepared by the Working Group for Mathematical Modeling and Systems Analysis, of the Soviet Committee for the UNESCO MAB program, deals primarily with work in the field of analytical modeling (although in some articles the mathematical results are interpreted in relation to specific natural situations). In compiling this collection, we did not presume to cover all of the directions of work pursued in the USSR in the area of analytical modeling in ecology. On the contrary, emphasis was laid on only one direction, but a rather important one in our opinion, namely questions of diversity in ecosystems. The articles in this collection can be divided into three main groups, according to the nature of analyzed diversity: diversity of dynamic modes and factors responsible for them in ecosystems; mechanisms of maintaining genetic diversity; spatial heterogeneity of ecological and population genetics system.

Research on these problems,which appear heterogenous from a specific vantage point,can be prefaced by the following statement: consideration of the substantially nonlinear interactions in modeling ecological and population genetics system (even in an extremely simplified form) of necessity leads to the existence in such systems of a wide diversity of equilibrated states, dynamic modes and spatial structures. This diversity is the main cause of the "counterintuitive" nature of the systems' reaction to exogenous factors and diverse threshold effects.

The source of qualitative differences in reactions to the same factor by similar (at first glance) systems (or the same system to seemingly similar factors) is expressly the diversity generated by the substantial nonlinearity of biological systems. Such phenomena cannot be comprehended if we confine ourselves to conceptions of close to linear systems, not far from equilibrium, that are spatially and functionally almost homogeneous.

Forecasting the behavior of natural systems (particularly in response to industrial factors) should be based on in-depth studies of nonlinearity and ensuing diversity of these systems.

In conclusion, we shall make two comments concerning the situation that has presently developed in mathematical modeling of systems on the supraorganismic level (populations and ecosystems):

1. Within the framework of mathematical ecology, studies are being made virtually exclusively of ecosystems formed through evolution, which consist of populations that are no longer subject to evolution. On the other hand, population genetics deals with evolution of isolated populations that are,so to speak, removed from

ecosystems. Apparently, here too it is time for synthesis, since the structure and function of ecosystems can be understood profoundly only with consideration of their evolutionary origin, the co-evolution of species that make them up. At the same time, the rate and direction of evolution of different populations are determined primarily by their interaction with other populations in the ecosystem.

2. A rather limited set of mathematical approaches and methods, which are used constantly and by everyone, has developed in mathematical ecology and genetics, whereas traditional methods are actually not always by far adequate to the substance of biological problems. At the same time, systems of concepts and approaches have been developed in different branches of mathematics, which may be useful in the study of ecological problems, but unfamiliar to the creators of models. The specific attempts made to fill these gaps in part, which were mentioned in these comments, are reflected in some of the articles of this collection.

Contents

10,657
CSO: 1840/999

PHYSIOLOGY

UDC: 591.1:612.84.88

FUNDAMENTALS OF COMPARATIVE PHYSIOLOGY OF SENSORY SYSTEMS--A TEXTBOOK

Leningrad OSNOVY SRAVNITEL'NOY FIZIOLOGII SENSORNYKH SISTEM: UCHEBNOYE POSOBIYE in Russian 1980 pp 2-4, 241-243, 246-247

[Annotation, foreword, conclusion and table of contents from book "Fundamentals of Comparative Physiology of Sensory Systems--a Textbook", by A. I. Konstantinov, V. A. Sokolov and K. A. Bykov, Leningrad "Order of Lenin" and "Order of Red Banner of Labor" State University imeni A. A. Zhdanov, Izdatel'stvo Leningradskogo universiteta, 248 pages, illustrated]

[Text] This textbook deals with descriptions of the structure and functions of the main sensory systems of invertebrates and vertebrates on different levels of evolutionary development. In addition to the general description of sensory systems, current conceptions are discussed with regard to mechanoreception, lateral line organs, gravitational sensory system, hearing, echolocation, chemoreception, photoreception and vision.

It is intended for undergraduate and graduate physiologists and zoologists at universities, medical, pedagogic and agricultural institutes.

Introduction

Comparative physiology of sensory systems emerged as an independent discipline relatively recently, and it is taught at the biology faculties of the leading universities of our country. This is attributable to several reasons. In the first place, the functions of sensory systems determine to a significant extent the patterns of formation of adequate behavior of animals on different levels of evolutionary development. The comparative features of these patterns constitute an important part of theory of evolution of the animal kingdom. While there is a basic similarity of fundamental mechanisms of activity of sensory systems, the ecological distinctions of different groups of animals coordinate not only reception processes, but "correlation" reactions of species and, within them, of individuals, to various environmental factors. In this sense, it is unquestionable that sensory systems play an important part in such decisive manifestations of animal biology as intraspecific correlations and correlations between species in a biocenosis.

In the second place, animals' spatial orientation is related to the activity of sensory systems. Orientation is, in essence, a function of sensory systems that is of enormous importance to the life of an organism, population and species, since it serves all vital situations, not only distant and short migrations, but

to the search for food, reproduction, care of offspring, avoiding danger, etc. Thus, orientation is one of the most important means of assuring the existence of living organisms.

In the third place, comparative physiology of sensory systems has many applied implications, in view of the emergence of such related disciplines as engineering biology and bionics. Comparative physiological investigation of the mechanisms of various functions is the biological foundation of these new directions, an inexhaustible supply of original structural designs and new ideas. Suffice it to mention, in this regard, areas of human endeavor such as development of biological means of controlling agricultural pests, use of various repellants to repel and attract animals, as well as modeling of engineering devices.

All of the foregoing makes it obvious that comparative physiology of sensory systems as a scientific discipline can potentially draw a broad group of professionally concerned students. However, it had been difficult to study the subject of this discipline because of the lack of a textbook that would combine the structure and functions of sensory systems of invertebrates and vertebrates.

The authors have tried to fill this gap in the present textbook, on the basis of a lecture course of the same name that is offered at the biological and soil faculty of Leningrad University imeni A. A. Zhdanov, and to provide as complete an idea as possible on this branch of physiology, on the basis of the most recent information gleaned from the latest summaries and manuals by Soviet and foreign authors.

The work was distributed among the authors in the following manner: V. A. Sokolov wrote the fourth section (Chemoreceptor Sensory Systems), K. A. Bykov wrote the fifth (Photoreception and Vision); the first (General Description of Sensory Systems), second (Mechanoreception) and third (Acousticolateral Reception) sections were written by A. I. Konstantinov, who also did the overall editing. The conclusion was written jointly by these authors.

The authors express their profound appreciation to S. M. Vereshchagin and V. P. Morozov, doctors of biological sciences, for their valuable advice and comments, which they voiced when they reviewed the manuscript.

N. V. Burikova and V. A. Kovalev, on the staff of the department of comparative physiology, assisted in writing up the manuscript, and the authors express their appreciation to them.

Conclusion

As the reader was able to see for himself, coding information, distinguishing between the different features of complex stimuli and selection of biologically significant signals constitute the main function of sensory systems on any level of evolutionary development of the animal kingdom. The peripheral mechanisms of this function have much in common in different organisms, both in homologous and parallel phyla, which is apparently related to their common biological tasks. The receptor cells of sense organs demonstrate a distinct parallel with regard to the part that is organized in the form of kinocilia or microvilli and their derivatives--stereocilia--that interact directly with some stimulus or other, in spite of the divergent

pathways and times of phylogenetic development of specific types of multicellular animals. Thus, evolution of receptor cells of sensory systems was always based on a cell supplied with flagella or microvilli and their derivatives. Perhaps this organization of receptor cells is a reflection of the origin of multicellular organisms from Flagellata, since flagella of the latter are functionally linked with the so-called ocellus [simple eye] that performs either a receptor or synthetic function, depending on illumination.

However, each level of development of sensory systems is characterized by specific structural distinctions and, first of all, central mechanisms. It should be noted that the higher the level of phylogenetic development of a group of animals, the larger the number of nerve and receptor elements representing their sensory systems. An increase in number of elements in sensory systems is associated with morphological and functional differentiation of peripheral receptor and ancillary elements, as well as central neurons and pools thereof, complication of interneuronal interactions which leads, in particular, to specialization of modeally specific and nonspecific zones in the brain. These zones are regions of the brain to which signals come that are formed, in some way or other, as a result of convergence of multisensory afferentation. Intersensory interactions are limited to this on the lower levels of evolution of sensory systems. At the later stages of development, there is differentiation of associative centers on different levels, because of which there is implementation of broad intersensory interactions, in the first place, and regulatory influences on underlying afferent and efferent centers, in the second place.

In essence, intersensory interactions occur in the very earliest stages of phylogenetic development. However, these processes are originally primitive at these stages, since they are based on a diffuse type of organization of the nervous system. The central processes of sensory neurons differing in modal specialization form a diffuse plexus into which come the terminals of intermediate or polyvalent neurons. In other words, multisensory convergence occurs in diffuse neuropil with the switching to neurons of the second order, whereas afferentation is wanting in modal specificity at the very start of the pathway. This is possible only on the level of development where the motor system is too poorly differentiated, while the diversity of motor acts is limited to a minimum. Nevertheless, even in the most primitive animals, some reflex arcs involved in more complex coordination acts, for example contractions in different directions of the muscle of the oral sucker [disc] of Actinia, under the influence of comestible and noncomestible objects on chemoreceptors and mechanoreceptors (Section 4, Chapter 1), are apparently specific. Differentation of the motor system evolved concurrently with development of increasingly fine coordinations which, in turn, required differentiation of specific pathways, since formation of working motor acts requires, in the first place, detailed discrimination of stimuli and, in the second place, that the signals be addressed to specific muscle groups. These patterns are demonstrable in the evolution of the nervous system of any phylar lines.

Appearance of bilateral symmetry, concentration of the main receptor systems in the anterior end of the body and, finally, formation of a cerebral ganglion, or brain, at the level of higher turbellaria was the start of differentiation of suprasegmental afferent nuclei. At the later stages of phylogenesis of protostomatic animals (starting with the errant polychaeta) there is formation of associative centers: fungiform body, central body, protocerebral pons in the order of Annelida--Arthropoda, the procerebrum in higher gasteropod mollusks, etc.

The main functional distinction of associative brain centers is their polysensory nature, i.e., capacity to receive influences from different sensory systems.

Essentially the same processes are observed in evolution of the central apparatus of vertebrate sensory systems: stage-by-stage cephalization of ascending pathways associated with formation of sensorimotor and associative centers on different levels (stages) of the central nervous system. In the vertebrate order, the nervous system achieves substantially greater morphological and functional differentiation, the most important element of which is corticalization of functions and, which is particularly important, sensory ones. Expressly this led to the progressive development of thalamocortical systems, the highest integrative levels of the brain, which are related to the most complex forms of behavior.

Gradual formation of multichannel transmission of signals to the higher stages of the brain is one of the important results of evolution of sensory systems. This property is manifested already on the receptor level in the form of specialization of different elements with increasing complexity of organization in the phylogenetic order; an increasing number of specialized channels can be singled out of the same sensory system.

Duplication of communication channels is, as we know, one of the means of assuring the reliability of sensory systems. Appearance of such channels in highly organized animals and man apparently reflects the general tendency toward refinement of construction of the brain and increased reliability of its sensory systems.

Thus, the vector of evolution of peripheral and central elements of the sensory systems is directed at development of animals' capacity to receive increasing information about the environment, analyze the signs of complex stimuli by breaking them down into an increasing number of elements, and identifying the ones that elicit adaptive behavior and spatial orientation.

Contents

10,657
CSO: 1840/999

TEMPERATURE COMPENSATION AND BEHAVIORAL HOMEOSTASIS

Leningrad TEMPERATURNAYA KOMPENSATSIYA I POVEDENCHESKIY GOMEOSTAZIS in Russian 1980 (signed to press 14 Jan 80) pp 2, 121-122

[Annotation and table of contents from book "Temperature Compensation and Behavioral Homeostasis", edited by K. P. Ivanov and A. D. Slonim, Scientific Council for Complex Problems of Human and Animal Physiology and Institute of Physiology imeni I. P. Pavlov, USSR Academy of Sciences, Izdatel'stvo "Nauka", 1150 copies, 124+ pages]

[Text] This collection submits the results of experimental research dealing with metabolic compensation on the tissular and organic levels. The authors expound a new conception of gradient of temperature functions of different systems (Q_{10} gradient) and possibility of using it to explain ecological and physiological relationships in poikilothermic and homoiothermic organisms; data are also submitted on changes in temperature dependence [function] of tissular metabolism as related to temperature adaptation and brief changes in ambient temperature. The collection is of interest to physiologists, ecological zoologists and biologists in broad specialties concerned with thermophysiology and thermobiology.

Contents

10,657
CSO: 1840/999

UDC: 612"735":613.6

BIORHYTHMS AND WORK

Leningrad BIORITMY I TRUD in Russian 1980 (signed to press 1 Feb 80) pp 2-3, 142-143

[Annotation, introduction and table of contents from book "Biorhythms and Work", edited by A. D. Slonim, Scientific Council for Problems of Applied Human Physiology and Institute of Physiology imeni I. P. Pavlov, USSR Academy of Sciences, Izdatel'stvo "Nauka", 5500 copies, 144 pages]

[Text] This book deals with the distinctions of rhythms of work actions and man's fitness for work [efficiency], as well as changes in biorhythms during the work process, as part of the general teaching on biological rhythms and, at the same time, a section of industrial physiology and ergonomics. There is a special chapter dealing with methods of studying rhythms in relation to performance of work, as well as an appendix presenting some of the mathematical aspects of rhythms of work processes. References 185, tables 15, figures 25.

Introduction

Physiologists are concerned with work as the chief form of man's active behavior. At the same time, studies of industrial physiology have much applied importance. It is imperative to take into consideration the condition of a working man and distinctions of his work activities with reference to all measures to improve health conditions and effectiveness of production. Physiological data are used extensively in ergonomics, organization of work, industrial hygiene and work safety.

Among the numerous data of this nature, the links between man's biological rhythms and his work activities are important. Work alters the rhythms of many physiological processes. For this reason, information about biorhythms is presently taken into consideration in solving the most diverse problems in the area of organization of work, upbringing and man's behavior in general. This interest was undoubtedly due to the great strides made and rapid rate of development of the science dealing with biological rhythms in the second half of our century. At the present time, wide circles of researchers are interested in biological rhythms as a promising subject and important aspect of scientific research.

The links between biological rhythm and performance of work are of considerable interest to theoretical research on human physiology. Work is a most important exogenous factor for people, which affects formation and alteration of rhythms of different physiological processes. In addition to changes and synchronization under the influence of work, there may also be disturbances of many rhythms when

man's work becomes the source of perturbations, which are occasionally transient and insignificant, but in some cases prolonged and have a substantial effect on health.

The nature and conditions of work constitute a powerful factor that affects the condition of man, his health and development. These influences affect a wide spectrum of rhythms, ranging from high-frequency rhythms of electrical activity of muscles and the brain to circadian, as well as monthly and annual rhythms of activity of the whole organism. Changes in rhythms are often an early and sometimes the first sign of the effect of work on man.

Contents

10,657
CSO: 1840/999

UDC: 57.034

TIME ENVIRONMENT AND BIOLOGICAL RHYTHMS

Leningrad VREMENNAYA SREDA I BIOLOGICHESKIYE RITMY in Russian 1981 (signed to press 10 Dec 80) pp 2-4, 129

[Annotation, foreword and table of contents from book "The Time Environment and Biological Rhythms", by Natal'ya Ivanovna Moiseyeva and Vladimir Mikhaylovich Sysuyev, Scientific Council for Problems of Applied Physiology, Institute of Evolutionary Physiology and Biochemistry imeni I. M. Sechenov, USSR Academy of Sciences, Izdatel'stvo "Nauka", 5450 copies, 128 pages]

[Text] This monograph deals with theoretical and experimental examination of biorhythms in the range of fluctuations with periods of several seconds and minutes to circadian and multiday rhythms. It was demonstrated that there is circadian and ultradian rhythm in many physiological functions related to adaptive and adjustment activity of an organism; many of the specific methods used to assess the functional state of both the autonomic and psychoemotional system of subjects are described. The authors formulate and solve the problem of determining the informativeness of time-related characteristics of biorhythms to assess the functional state of an organism both in the course of the adaptation process with change in parameters of exogenous social and geophysical synchronizers, and in the course of treatment of neurological diseases. The book is intended for physiologists, biologists, clinicians and sports medicine physicians. References 190, figures 15, tables 40.

Foreword

The existence of living organisms in a complex and dynamic environment is possible only because of continuous interaction with the environment and an unceasing process of adaptation to changing exogenous conditions. The rhythmic nature of processes in an organism has been known since distant antiquity, it was known not only in Ancient Greece, but Anciet Egypt and Mesopotamia. The medieval followers of Plato, for example, Paracelsus, already considered the dependence of course of diseases on exogenous rhythms (Jovanovic, 1977). However, the science of biological rhythms, which has such deep roots, emerged and was formed only in the second half of the 19th century and start of the 20th. In 1935, the first International Society for the Study of Biological Rhythms was founded in Switzerland, and in 1971 it was transformed into the International Society of Chronobiology in the United States.

One of the main questions of biorhythmology is the origin of biological rhythms and means of their regulation. In essence, for a long time already, no one questioned the fact that endogenous mechanisms are involved in both formation and

constant regulation of biological rhythms, and that this regulation occurs under the influence of "time signals" [marks] from the environment. However, problems of the sources of these exogenous influences and mechanisms of their perception are far from being definitively resolved.

While it was chiefly the change in illumination that was originally considered the time-setting environmental factor, at the present time researchers are concerned with a broad spectrum of heliogeophysical and even cosmic factors.

In analyzing the significance of heliogeophysical factors in regulation of biorhythms, we discovered that they exert their influence in different ways. Thus, changes in earth's magnetic field affect formation of rhythm of physiological processes, whereas changes in solar activity (and related weather factors) primarily modulate biological rhythms.

The biological rhythms of the organism formed in the course of ontogenetic development form a complex system, in which rhythms with a greater period modulate rhythms with a smaller period. According to our conceptions, this system is formed on the basis of the individual time scale of a given organism. The scope and variability of this intrinsic time scale in man and, accordingly, his subjective perception of time are related to his individual and typological distinctions, overall functional state of the organism and intensity of intellectual and mnestic activity, as determined by the volume of processed information and work done.

The influences to which the organism is constantly submitted may occur regularly, in accordance with a specific stereotype or, on the contrary, they may be unpredictable (stressor factors). One must also have a wide "choice" of values of functions in order to react in an optimum way to the regularly occurring changes in the environment, but the regulatory mechanisms that permit reaching these values must not be triggered at the moment of exposure to environmental factors, but before this, "forestalling" them. For an optimum reaction to an unpredictable factor, the organism must have a developed capacity to rapidly find the values for degree of function that are the most adequate to a given situation, among the entire existing range thereof.

A forestalling reaction occurs through the period and phase of a given rhythm that provide for maximum functional capacity at a specific time of day, and the better the circadian curves are organized, the higher adaptability is. An adequate reaction to unpredictable factors is provided by the amplitude of fluctuations, and the wider their spread, the greater "choices" the organism has and, accordingly, the more adequate its reaction.

In view of these distinctions, we have proposed the use of the structure of biological rhythms as a criterion of adaptability and thereby use them to forecast both professional fitness for a job under extreme conditions and the outcome of a disease (Moiseyeva, 1978a, 1978b).

The following are good prognostic signs: 1) distinct organization of the circadian curve; 2) relatively high mean values and scatter of these values over a 24-h period; 3) relatively constant position of the acrophase when tested repeatedly for several days.

In conclusion, it must be stated that the study of biological rhythms hands a new tool to physicians and biologists for evaluating the functional state of the body, which enables them to study variability, i.e., the patterns of deviations from the average state, which is much more important than the study of this average state.

Contents

10,657
CSO: 1840/999

CHAPTER 2. THE GRAVITATIONAL SENSORY SYSTEM

Leningrad OSNOVY SRAVNITEL'NOY FIZIOLOGII SENSORNYKH SISTEM in Russian 1980 pp 52-63

[Chapter 2 of Section 3 from book "Fundamentals of Comparative Physiology of Sensory Systems" by A. I. Konstantinov, V. A. Sokolov and K. A. Bykov, Leningrad "Order of Lenin" and "Order of Red Banner of Labor" State University imeni A. A. Zhdanov, Izdatel'stvo Leningradskogo universiteta, 248 pages, illustrated]

[Text] All organisms that ever lived on earth developed in the presence of the effect of gravity on them or, in other words, in earth's gravity field.

The orientation of animals in earth's gravity field differs from orientation with respect to any other physical features of the environment perceived by the sense organs. This difference is related to two distinctions of the gravity field. In the first place, it is virtually constant in both magnitude and direction toward the earth's surface. In the second place, it is "all-penetrating," i.e., it affects any body on earth and cannot be "shielded" from it.

For orientation in relation to earth's gravity field, most animals have a "body position sensor," i.e., a special otolith organ that reached more or less refinement in the course of evolution, but nevertheless is based on the same principle. The organ of equilibrium consists of two parts: the "trial [testing] mass," i.e., an otolith that has more or less free mobility within the organ and a system of receptors that perceive the position or displacement of this mass in the organ. Any deviation of body position is associated with displacement of the "trial mass" (otolith, otoconia, otolith membrane), stimulated by the appropriate group of receptors of the equilibrium organ. The signal from these receptors is processed by the central nervous system [CNS] which sends the command signal to muscles to correct the position of the body.

The structure and functions of this receptor organ have been discussed in detail in the comprehensive monograph by Ya. A. Vinnikov et al., "Gravity Receptor" (Leningrad, 1971).

Statocysts of Invertebrates

Apparently, development of a model of a gravity receptor was first defined in unicellular organisms having a statocystoid organelle. In infusoria, this refers to Mullerian vesicles 10-18 μm in diameter filled with round mineral concretions or otoconia. In Coelenterata (jellyfish) the gravity receptors are of

two types, statocysts proper and lithostyles, which are encountered in both Scyphomedusae and Medusae. Statocysts demonstrate all the transitional forms, ranging from a small indentation to a closed vesicle. Lithostyles are flask-shaped. They apparently develop from tentacles and differ in size, as well as structural complexity. The so-called rhopalium, or marginal organ, is an example of a large lithostyle. The numerous lithocytes of the medusal rhopalium function as an overall mass, even though they consist of absolutely independent cells. Thus, in the Coelenterata, the "trial mass"--otoconia--is still directly linked with the cell --lithocyte--cytoplasm, in which it develops.

The cnidoblast is the receptor cell of Coelenterata. The cnidoblast tapers down on the apical surface to a cnidocil, crowned with a typical curved flagellum, the kinocilium, and surrounded by 18-22 stereocilia. Thus, the cnidocil is virtually no different from the surface of the receptor hair cells of the acousticolateral line of vertebrates.

In Tamaricaceae, the gravity receptor (aboral organ) apparently appears first; on the cellular level of organization it contains all of the main elements that subsequently became inherent in more highly organized animals. Turbellaria worms and nemerteans still use lithocytes located in the statocyst cavity as a "trial mass." Primary sensory cells with kinocalic first appear in segmented worms (Annelida), while their "trial mass" consists of otoconia or grains of exogenous sand. However, the most refined form of organization of the statocyst, which changes into a genuine equilibrium organ is observed in crustaceans and mollusks (Figure 16 [none of the figures is reproduced]).

Statocysts generally consist of closed cavities filled with fluid, containing a statolith or statoconium (particles analogous to the otolith and otoconia of the inner ear of vertebrates), which may be either of biological origin (secreted by the statocyst itself) or exogenous origin (for example, grains of sand), in different species. The cavity of the statocyst is lined with ciliate receptor cells, which are uniformly distributed in some animals and form accumulations that are called maculae in others, for example, cephalopod mollusks.

When the animal changes its position in space, the statoconia are displaced in the statocyst which, in turn, causes deflection of the cilia of receptor cells. The signals of receptor cells are transmitted to the CNS over static nerves. The direction and degree of deviation of the body from its initial position and various compensatory reflexes are determined from the interaction of statocyst receptors with one another and in the CNS with the afferent flow from other sensory systems.

In crustaceans, the statocysts are usually paired organs. They may be both in the head and abdomen. The statocysts of the head are innervated by the cephalic ganglion and those of the abdomen by the last ganglion of the ventral cord. In higher crustaceans, for example, the lobster, statocysts are located at the base of the first antennae.

In 1893, Kraydl offered convincing evidence of the fact that the statocyst is the equilibrium organ in the lobster. He succeeded in replacing the grains of sand in the statocyst with iron filings, and a magnet drawn toward the animal from the top forced it to turn over on its back.

The uneven walls of the crab's statocyst form two cavities, a vertical and horizontal one (Figure 16*a*). Passing a stream of water through the canals was found to be equivalent to turning the body. There are free hook-like pili in the posterior, vertical canal and these pili are arranged in groups in the lateral wall of the horizontal canal. There are filaments over the central sensory zone, while the pili that are in contact with the statolith form a spot (macula) at the base of the vertical canal.

The filiform pili [hair] are sensitive to rotation of the animal about the vertical axis, while the free hook-like pili are sensitive to rotation about the horizontal axis. The pili that interact with the statolith are considered to be the static receptors, the neurons of which do not adjust. Threshold displacement of the apex of a pilus constitutes 0.5 μm, and there is an optimum angle of inclination, with which the receptor discharge is at a maximum, for each type of hair. The filiform pili are receptors of accelerations and the frequency of their discharge depends on the direction of displacement. These receptors are capable of adaptation. The frequency of impulsation in the lobster's statocyst is at a maximum when the animal turns 80-120° about the transverse axis, and this is associated with reflex movement of the optic stalks. The action of the statocysts is antagonistic to that of stretch receptors situated at the base of the antennae, which control their movement.

In mollusks, statocysts are represented by paired spherical vesicles 50-500 μm in diameter, which are filled with a viscous fluid--statolymph--and contain one or many statoliths. The statocyst cavity is lined with sensory epithelium, which consists of sensory ciliate cells, each of which is surrounded by so-called support cells. The receptor cells of the statocyst are usually called hair cells, although unlike typical hair cells of vertebrates they are primarily sensory and have central processes. The number and size of sensory cells, as well as orientation of their cilia, differ in representatives of different classes of mollusks, and this leads to differences in functional capacity of their receptor elements. The statocysts are comprised of only 13-15 large receptor cells (40-60 μm in diameter) in Pulmonata and Opisthobranchiata mollusks (Figure 16*б*) and hundreds and thousands of sensory cells (5-10 μm) in bivalves and Prosobranchia.

Electrophysiological studies elucidated some of the details in the mechanism of operation of the receptor system of statocysts. At rest, derivation from the static nerve demonstrates background activity. Probably, this activity, which is not spontaneous, is attributable to the effects of statoconia on the cilia of receptor cells. The receptor cell shows no activity until it is in the lower part of the organ and is submitted to the pressure of the statoconia. The mechanism of excitation of a sensory cell of the statocyst is considered to be analogous to the mechanism of function of the receptors of the lateral line and vestibular system.

Statocysts of cephalopod mollusks (Figure 16*в*) are the most highly organized and, apparently, are not inferior to the vertebrate labyrinth in functional capacity. The study of gravity receptors is of special interest here, both in relation to the reactive mode of movement of these animals and the unusual similarity of their receptors to equilibrium organs of crustaceans and vertebrates. In the octopus, the statocysts have not only an endolymphatic cavity, but perilymphatic space that is wanting in the squid. But, in the octopus, only one acticrista protrudes into the statocyst cavity, whereas in the squid the number thereof is up to 11. Evidently, the presence of acticristae makes it possible to regulate movement of endolymph when the animal moves, just like the semicircular canals of vertebrates.

The main structures of the statocyst, the maculae, are supplied with otoliths and cristae invested with cupulae that are deflected when the endolymph moves, which first appeared in invertebrates. The maculae of cephalopods serve as gravity receptors, i.e., they provide for static equilibrium, whereas the cristae are receptors of angular accelerations that provide for dynamic equilibrium.

The octopus has a pair of statocysts, each of which is divided into three receptor zones (maculae with otoliths) directed in different planes and perceiving linear acceleration. In addition to linear acceleration receptors there are receptors of angular accelerations (cristae). There is interaction between these zones, both on the periphery and in the centers. Removal of one statocyst does not have a marked effect, while removal of both statocysts leads to disorientation, which is even greater when the animal is blinded. Stimulation of statocysts by rotation demonstrates compensatory reactions in the form of eye movements (nystagmus), which depend on the direction of the so-called "cutting moment" that occurs when the statolith is displaced.

The responses of statocyst receptors of crustaceans and arthropod mollusks to vibration have been recorded. The statocysts of gasteropod mollusks react not only to vibration, but low-frequency sound (20-2000 Hz).

Thus, the broad capabilities of statocysts were determined. As we have already stated, the statocyst system is functionally linked with other sensory systems, for example, visual, chemoreceptor and the system of stretch receptors. Thus, in gasteropod mollusks, the main integrative center is the cerebral ganglion, where the processes of statocyst receptor cells end. The statocyst receptor cells are functionally linked with the visual system and may have both an excitatory and inhibitory effect on one another. Some neurons of the cerebral ganglion of the Limnaeus snail [periwinkle?] react to adequate stimulation of the statocyst and eye. This is indicative of intersensory interactions in central neurons, which occur by means of convergence of heteromodal afferentation. Such interactions implement coordination of motor acts, regulation of muscle tone and adaptive behavior.

With the development of motor activity in animals, the system of the statocyst, which emerged as an organ of static equilibrium, changed into a sensory system capable of regulating animal behavior in three-dimensional space. In addition to vestibular function, this system is capable of seismoreception and vibroreception, and in some highly organized forms acoustic reception as well. This justifies consideration of the sensory statocyst system of crustaceans and mollusks as a sort of analogue of the acoustic and vestibular systems of vertebrates.

The Labyrinth of Vertebrates

The vestibular system of the inner ear of vertebrates consists of two parts: the bottom part is comprised of a sacculus and lagena, or cochlea, and the top of the utriculus and semicircular canals (Figure 17). All vertebrates usually have three semicircular canals (with the exception of some Cyclostomata who do not have a horizontal canal). The hair cells of the utriculus, sacculus and lagena of fish are collected in groups, the so-called acoustic spots, or maculae, and not infrequently, one part of the labyrinth may have several maculae. The membranous part of the labyrinth, which is filled with liquid endolymph, is situated in the bony labyrinth filled with perilymph. Both the utriculus and sacculus have one or

several otoliths. The otoliths of fish consist of aragonite with a specific gravity of 2.9, while those of mammals consist of calcite with specific gravity of 2.7. The hair cells of the semicircular canals are concentrated in ampullae, which are situated at the junction of the canal and utriculus. The hair cells are grouped in a cristae in each ampulla, and there is a gel cupula above the cristae (Figure 18). The hair cells transmit synaptically signals to the branched processes of neurons of the vestibular ganglion.

Functionally, the macula of the utriculus perceives the position of an organism in relation to the gravity field, i.e., it is a gravity receptor, whereas the ampullar cristae of the three semicircular canals located in three mutually perpendicular planes perceive angular accelerations. In fish, the maculae of the sacculus and lagena are essentially responsible for perception of vibration and sonic oscillations.

In lower vertebrates--fish and amphibians, organization of receptor structures of the labyrinth is based on type II cells, to which type I cells are added in higher vertebrates, starting with reptiles. It is quite obvious that type I cells, which first appeared in higher vertebrates, reflect not only overall improvement of organization, but a change in position in earth's gravity field, which required more universal and reliable transmission to the CNS of information received by receptor cells. Both types of receptor cells are crowned with a bundle of hairs consisting of 60-70 stereocilia and one kinocilium situated polarly in relation to them. The kinocilia are attached to the otolithic membrane with otoliths or otoconia, while the stereocilia freely support it or "comb it down." Displacement of the otolith membrane with change in position of the body in the gravity field is associated with appearance of cutting forces, as a result of which there is tangential bending of sensory cell hairs. The role of the solitary kinocilium apparently amounts to regulation of degree of slipping, pressure and accuracy of movement to initial positions of the otolithic membrane in the region of each receptor cell. As in other hair cells (neuromasts, cells of the organ of Corti), a constant potential--depolarizing or hyperpolarizing--is recorded in the layer of macular hair cells, depending on the direction of displacement of the pili. The causes of presence of constant potentials in the labyrinth have not been reliably determined. According to current conceptions, the receptor potential in hair cells, induced by displacement of the cupula in relation to the crista, in turn modulates the frequency of impulses in the vestibular nerve by means of depolarization or hyperpolarization of nerve ending dendrites in the region of synapses with bodies of hair cells.

The fibers of the vestibular nerve consist of processes of bipolar neurons which, together, form Scarpa's ganglion. The peripheral fibers join into several branches, which innervate the cristae of each of the three semicircular canals, as well as the maculae of the utriculus. The central fibers enter into the medulla oblongata and come in contact with the neurons of vestibular nuclei. The vestibular nuclei are the first level in the CNS where information about movement or change in spatial position of the body, coming from labyrinthine receptors, is processed.

As we have already noted above, angular acceleration in the plane of a canal, which functions like a torsion pendulum and in which there is a lag in endolymph movement in the presence of acceleration, as compared to movement of the canal wall, is a stimulus for any of the semicircular canals. In fish, a constant potential with an amplitude of 20 mV is recorded from the endolymph. During ipsilateral rotation

(with the ampulla to the rear) of a ray, at an angular velocity of 3°/s, the frequency of discharges in the nerve fiber going from the ampulla of the horizontal canal increases, and with contralateral rotation (with the ampulla to the front) it decreases. The frequency of discharges in the nerve fiber is related to linear or rotatory acceleration. The vertical canals react to rotation about any of the three axes, each canal in its plane. After discontinuing the stimulus (rotation), one observes aftereffects consisting of depression or intensification of the discharge in the nerve fibers. Upon rhythmic rocking of a ray, the change in frequency of impulses in its ampullar nerve either lags from the time of reversing the direction of movement, or else is ahead of it. The decrease in frequency after changing the rate of rotation corresponds to the coefficient of damping rate (friction moment) and lasts about 40 s, i.e., twice the time it takes for the cupula to return.

Several types of reactions were demonstrated in tracings derived from single fibers of the frog's vestibular nerve: 1) reaction to rotation consisting of appearance of spontaneous impulsation or depression thereof during rotation in two opposite directions; 2) reaction to inclination only; 3) reaction to both rotation and inclination; 4) no reaction to acceleration. Displacement of the cupula during acceleration occurs as a result of endolymph inertia, while resistance to friction in the thin canals serves as a damper for the entire system. Efferent impulses were recorded in the frog's ampullar nerve. The discharge frequency increases in fibers going from the horizontal canal during ipsilateral rotation and discharges stop entirely during contralateral rotation.

In cats and rabbits, four types of neurons differing in nature of change in impulse activity were demonstrated in response to angular accelerations or bending the head. The first type of neurons reacted by an increase in discharge frequency in response to ipsilateral rotation. This type of neurons was found in the vestibular nerve of the reticular formation of the cat's medulla oblongata and vestibular nuclei of the rabbit. The second type of neuron reacted in the opposite way from the first type. Impulsation frequency diminished during rotation in the ipsilateral direction and increased with rotation in the contralateral direction. These neurons have been described in the reticular formation of the cat's medulla and the rabbit's vestibular nuclei. The third type of neuron responded by acceleration of impulsation in response to rotation in both directions while the fourth, on the contrary, was characterized by inhibition of activity during rotation in both directions. The last two types of neurons have been found in the cat's vestibular nerve and rabbit's vestibular nuclei.

The neurons of the vestibular nuclei react not only to impulses from labyrinthine receptors, but signals elicited by movement of limbs in the joints and turning the body, as well as signals from internal organs. Thus, conditions for interaction between signals of different modalities already exist on the level of the vestibular nuclei of the medulla.

The cortical projection zone of the vestibular system of mammals consists of the anterior segments of the suprasylvian and ectosylvian gyri in the temporal cortex of both hemispheres.

Spatial Orientation

The question of significance of the vestibular system to spatial orientation of man and animals has been the subject of active discussion for a long time, in connection

with the hypothesis of Tsion [Cyon] (1879) concerning the vestibular system as the organ of sense of space. On the one hand, the significance of the vestibular system as a spatial analyzer is absolutized, and on the other hand emphasis is laid on involvement of other sensory systems in analysis of environmental spatial factors. In recent times, the second opinion has gained in popularity. Its proponents believe that normal orientation in relation to the direction of the force of gravity is possible by virtue of integration of sensory signals from the labyrinths, eyes, proprioceptors and tactile receptors. Thus, in man visual stimulation may compensate for the absence of labyrinthine stimulation. When there is a mismatch between vestibular and visual inputs in man, the "motion" syndrome occurs, whereas this does not happen in individuals wanting in a normal labyrinth. Probably, sensitivity to head movements may increase in weightlessness. Compensatory eye movements reach a maximum when the head makes a 60° turn. In man, the macula is deflected 30° to the back, so that if the head is bent 30° forward the utricular macula will be in horizontal position and will not perceive G forces. Such a compensatory mechanism exists in chicks and mice that have been kept for a long time in rotating chambers with high values of "d" [?].

Removal of one utriculus from fish leads to prolonged deviation of the eyes and fins; damage to the saculus and lagena has a significantly lesser effect. After destruction of both utriculi of the frog, it stops reacting to inclination of the body. As we know, a normal cat falls on all four legs, but a cat submitted to bilateral labyrinthectomy cannot do this. Visual sensations play a very large part in recovery of position in dogs, cats and man, and a much smaller role in rabbits and guinea pigs. If a labyrinthectomied rabbit is placed on its side on a table, it moves the head to normal position, but if a small board is put against the animal's other side, the normal position of the head is not restored. Consequently, asymmetrical stimulation of cutaneous receptors is important to recovery of position.

Hypotheses have been expounded concerning the significance of the vestibular system to navigational behavior of migrating birds. These hypotheses are based on the possibility that the semicircular canals of the labyrinth measure or calculate Coriolis' accelerations.

FIGURE CAPTIONS

16. pp 54-55. Diagram of organization of statocysts of crustaceans (*а*) and mollusks (*б*, *в*)

а) statocyst in open articulation of crab antenna (after Sandeman, Okayama, 1972):

г.в) groups of hairs
г.к) horizontal canal
н.в) filiform pili
с.в) free hook-like pili

б) statocyst of common snail (Helix vulgaris) (after Kovalev, Sokolov, 1977):

б.м) basilar membrane
в) vacuoles
г.к) glial cell
м.к) muscle cells
н) static nerve
о.к) support cell

п.о) dense connective membrane of statocyst
р.о) friable connective membrane covering pedal ganglion
с) statoconium

в) diagram of structure of left statocyst of the Octopus vulgaris, lateral view (after Young, 1950):
а.к) acticrista
в.м) ventral crista
з.с) posterior sinus
к) cupula
к.К) Kelliker's canal
в.к) lateral crista
о) otolith
м) macula
н) nerve
н.з.к) nerve of posterior crista
н.м) macular nerve
н.м.к) nerve of medial crista

17. p 59. Diagram of structure of vertebrate labyrinth (after Fresh, 1936)
1) fish
2) turtles
3) birds
4) mammals
б.м) basilar membrane
л) lagena
с) sacculus
у) utriculus
ул) cochlea

18. p 60. Crista (а) and macula (б) of vestibular organ of mammals (after Netter, 1953)
б.м) basilar membrane
в) pili
в.к) hair cells
ж) gelatinous layer
к) cupula
н.в) nerve fiber
о) otoconia
п.к) supporting cells

10,657
CSO: 1840/999

UDC: 612.821.6

REPRODUCTION OF 'PASSIVE' AVOIDANCE IN RATS WITH ADMINISTRATION OF PHARMACOLOGICAL AGENTS

Moscow ZHURNAL VYSSHEY NERVNOY DEYATEL'NOSTI IMENI I. P. PAVLOVA in Russian Vol 31, No 1, Jan-Feb 81 pp 158-163

[Article by P. D. Shabanov, Department of Pharmacology, Institute of Experimental Medicine, USSR Academy of Medical Sciences, Leningrad, submitted 26 Mar 79]

[Text] The desire to identify specific neurophysiological mechanisms upon which animal and human memory are based is reflected in studies of different stages of formation of an engram and its expression. The question of mechanisms of reproducing engrams is important.

To date, there is no universally recognized model to study the system of recall [reproduction]. Most often, the phenomenon of recovery of memory following retrograde amnesia caused by various deleterious factors--electroconvulsive shock, carbon dioxide, inhibitors of protein synthesis and others [11, 13, 21-23]--is used for this purpose. The polemic is concentrated around the question of genesis of loss of skill: is it a reflection of impaired consolidation [15, 19] or recall [2, 21, 23]. However, the definitely formulated properties of consolidation [16], the possibility of spontaneous [20, 25] and evoked--by reminding [5, 6, 23]--recovery of memory, as well as the insignificant differences in the amnesia gradient under the influence of a deleterious agent at different intervals after training in rats [21], are indicative of the need to continue with studies of the mechanisms of recall.

In our laboratory, systematic studies were pursued of the effects of various pharmacological agents on learning [training], consolidation, retention of engram [7, 8] and on processes of organization of cerebral systems in pharmacological control of memory [1]. It was logical to continue investigation of these mechanisms by studying the effects of pharmacological agents on the system of recall.

Recently a specific correlate of temporary association was singled out--a delayed evoked potential, which permits analysis of recall processes [3, 4], but because of the methodological difficulty and limitations of using this criterion, many researchers continue to use the reminding phenomenon [6], as well as some autonomic and electroencephalographic components of the behavioral reaction [2] to study the recall system.

This article deals with experimental analysis of reproduction of the conditioned reaction of so-called passive avoidance in rats submitted to electroconvulsive shock with administration of various pharmacological agents and use of other factors.

Methods

These studies were conducted on male mongrel rats weighing 180-200 g, 90-120 days old. The conditioned "passive" avoidance reaction (PAR) was developed on the basis of single electrocutaneous reinforcement using a modification of the method in [9]. The experimental unit consisted of two chambers: a large illuminated one and a small dark one, with an electrified floor, connected by a round opening. To produce the PAR, the rat was put in the middle of the illuminated chamber with its tail toward the opening into the dark one. The animal inspected the light chamber, found the opening and passed into the dark one. The latency period was recorded from the moment the rat was placed in the chamber until it had moved completely into the dark part. The animal was allowed to remain there for 15 s (to check that it did not go into the dark chamber by chance), after which 50-Hz alternating current was delivered to the wire flooring for 2-3 s, pulses lasting 10 ms. The power was selected individually for each animal. The hole into the dark chamber was kept open. We observed animals that ran back into the illuminated chamber for 3 min. The PAR was considered to be developed in one test in rats who did not enter the dark chamber in this time. The rats that returned to the dark chamber within 3 min during training were excluded from the experiment. The trained rats were taken out of the illuminated chamber and put in their cages. The experiment lasted an average of 4 min. To check retention of the PAR, the trained animal was put in the illuminated chamber for 3 min; if it entered into the dark chamber it was rated as an animal with PAR amnesia. Testing 10, 15, 30, 45 min, 1, 2, 4, 6, 8, 24 and 72 h after development of the reaction revealed that none of the animals placed into the illuminated chamber for 3 min at the above intervals went into the dark chamber. Spontaneous forgetting of the PAR was recorded on the 6th-7th day after training; this was observed in half the animals on the 10th-11th day. Waking rats were submitted to electroconvulsive shock (ECS; 20 mA, 500 ms) 2 h after development of PAR. The electrodes were applied to the cornea. ECS 2 h after development of PAR and during test after 24 h revealed a marked decline of spontaneous motor and exploratory activity in an "open field," which was indicative of incomplete recovery of the animals' nervous system from the extreme effect of ECS, whereas testing after 72 h failed to demonstrate a reliable difference between their motor activity and that of intact animals. On this basis, we selected an interval of 72 h between training the animal and subsequent testing. The pseudo-ECS procedure did not affect reproduction of the PAR.

As a result of testing retention of the PAR 72 h after developing the reaction, under conditions similar to training conditions, we were able to separate the animals into two groups: with amnesia (30%) and without PAR amnesia (70%). We evaluated the effects of pharmacological agents on reproduction of the PAR 2-3 h after test screening in both groups. The agents were injected intraperitoneally 1 h before testing, in a volume not exceeding 0.5 mℓ. We tested the following agents: central nervous system stimulants--caffeine 5 mg/kg and ethymizole 1.5 mg/kg; gamma aminobutyric acid (GABA) 200 mg/kg; cholinergic agents--carbacholine 0.01 mg/kg, arecoline 0.5 mg/kg and nicotine 1 mg/kg; anticholinergic agents--spasmolytin 10 mg/kg, methyldiazil [metamizil] 0.5 and IEM-506 [diamine imidazole dicarboxylic acid derivative or pyrazolidine carboxylic acid derivative] 5 mg/kg. The animals were given 0.5 mℓ saline as a control.

The procedure of "nonspecific reminding" was performed in a glass cylinder, 20 cm in diameter and 35 cm tall (exposure to a bell, 80 dB, 15 s).

The sample of animals for each tested pharmacological agent constituted at least 30 rats. The experimental results were submitted to statistical processing with the use of Student's criterion. We singled out the alternative sign (reduction or appearance of amnesia gradient) and latency period in all animals.

Results

The results are listed in the Table. We see that in testing control animals with PAR amnesia there was a tendency toward spontaneous restoration of the reaction (in 20% of the animals). A sonic stimulus had the maximum capacity to restore a forgotten PAR. In this group, amnesia was not observed in 80% of the animals. Of the pharmacological agents, maximum activity was demonstrated for GABA (70% gradient of restoration of forgotten PAR) and cholinergic agents (nicotine, carbacholine and arecoline, 61.9, 60 and 50%, respectively). A comparable effect was observed with injection of methyldiazil, an antagonist of muscarine receptors (60%). A less marked effect was noted after injection of the central nervous system stimulants, ethymizole and caffeine, as well as anticholinergic compounds IEM-506 and spasmolytin (recovery gradients 50, 36.36, 50 and 10%, respectively.

Effects of different factors on recall of PAR in rats tested 72 h after training

Factor	Dose, mg/kg	% rats with restored reaction after forgetting PAR	% rats who forgot reaction out of group with retained PAR
Saline	0.5 mℓ	20	0
Ethymizole	1.5	50	0
Caffeine	5.0	36.36	19.35
Carbacholine	0.01	60	19.05
Arecoline	0.5	50	15
Nicotine	1.0	61.9	3.85
Spasmolytin	1.0	10	14.29
Methyldiazil	0.5	60	15
IEM-506	5.0	50	5
GABA	200.0	70	0
Sonic stimulus		80	10

The methodological distinction of the experiment (test screening) enabled us to also test the effects of pharmacological agents on recall of PAR in animals without amnesia. Ethymizole and GABA did not impair reproduction of the reaction, unlike caffeine, cholinergic and anticholinergic compounds, which elicited amnesia in 14-20% of the animals.

Discussion

The method of developing the PAR in one test followed by ECS is used the most often to study recall processes [10, 18, 23]. The influence of ECS on memory, interpreted in favor of impairment only of consolidation [15, 19], is justifiably questioned at the present time [22, 25]. Interpretation of retrograde amnesia induced by ECS from the standpoint of the hypothesis of impaired consolidation

implies that amnesia should be irreversible in this case. The proponents of the hypothesis of impaired consolidation attribute restoration of a lost skill either to partial amnesia or intensification of retention of the skill in poorly trained animals using the reminder procedure [6, 15]. In opposition to the hypothesis of impaired consolidation there are quite a few data that stress the transient nature of retrograde amnesia induced by ECS--recovery of forgotten skill spontaneously or by reminders, reduction of amnesia gradient with increase in time spent by the animal in the experimental unit, change in interval between ECS and subsequent testing and with repeated testing of animals [5, 11, 20, 23]. However, the deleterious effect of ECS on the process of consolidation or recall [retrieval, reproduction] is ultimately determined by the correlation between stability of the initially developed skill and force of amnesia-causing factor. Nevertheless, the fact that the "passive" avoidance skill is restored after ECS, even if the latter was used fractions of a second after training [18], as well as the negligible differences between the gradient of amnesia induced by ECS immediately after training and 24 h later, confirm the hypothesis of impaired recall [21], in contrast to the hypothesis of impaired consolidation.

Considering one of the most important properties of consolidation--completion thereof within a finite period of time which, according to most researchers and our findings, does not exceed 2 h [16], we used a 2-h interval between training and ECS in the belief that consolidation occurred within this period and that ECS then acted on a formed engram. Since there has been repeated indication in the literature that a formed engram is highly stable [3], it can be assumed that the observed amnesia gradient was the result of predominant damage to the recall system. Thus, use of ECS in the presence of a formed engram enabled us to methodically separate the successive stages of engram formation and recall.

The marked increase in gradient of restoration of forgotten reaction under the influence of an audio stimulus ("nonspecific reminder") is the most convincing argument in favor of impaired PAR recall in our experiments. The fact that the sonic stimulus was delivered under other than training conditions is indicative of nonspecific increase in excitability of brain structures involved in expression of the skill. Pharmacological agents differing in mechanism of action had a similar effect on recall of the PAR. In this respect, GABA and cholinergic compounds were the most effective.

The beneficial effect of cholinergic compounds on PAR recall is consistent with the numerous data indicating that they improve learning and memory processes [17], and it confirms the involvement of acetylcholine in recall processes. However, the similarity of effects of anticholinergic agents (methyldiazil and IEM-506) and GABA is indicative of the role played by nonspecific factors (motor activity, emotional and motivational elements of reaction) in this skill. There has been indication of the significance of these factors to manifestation of the PAR elsewhere [14]. Our data concerning improvement of recall under the influence of GABA conform with those that indicate an improvement of memory by means of blocking GABA transaminase, an enzyme that utilizes GABA, p-dipropyl acetate, associated with an increase in GABA content in the brain.

It should be noted that the low percentage of amnesia cases evoked by pharmacological agents (not exceeding 20%) is not an indication of the mildness of their amnesia-inducing effect, in view of the significant stability of a developed PAR.

The impairment of recall induced by caffeine is apparently attributable to the large dosage of this agent. It is known that in small doses (1 mg/kg) caffeine improves the PAR and in large doses (20 mg/kg) it impairs it [10]. The analogous effect of cholinergic agents confirms the conception [12] of optimum concentration of acetylcholine needed for memory and learning processes. In this case, an increase in activity of cholinergic neurons apparently impairs reproduction of the PAR.

Typically enough, under these conditions (in animals without amnesia), GABA and ethymizole did not impair recall of PAR. Evidently, these compounds are optimal for this reaction. Moreover, as repeatedly mentioned in the works of Yu. S. Borodkin et al. [1, 8], ethymizole is instrumental in fixing a skill and retention thereof for a long time after single administration of this agent. It should be noted that the effect of ethymizole was manifested regardless of the nature of the skill, for which reason it was classified in the group of nonspecific connectors [8] which, by analogy to specific connectors [24], alleviates consolidation and storage of an engram. In addition, ethymizole caused faster formation of stable artificial functional associations [1, 7], which is one of the recall models, in patients suffering from motor disorders of central origin.

Conclusions

1. Nonspecific activation of cerebral structures responsible for expression of a skill plays a substantial role in the mechanism of retrieval [or recall] of an engram.

2. Cholinergic mechanisms of the brain and GABA have some involvement in activity of the recall system.

3. Ethymizole and GABA are instrumental in forming optimum conditions for recall of the conditioned "passive" avoidance reaction in rats.

BIBLIOGRAPHY

1. Borodkin, Yu. S. and Krauz, V. A., "Pharmacology of Short-Term Memory," Moscow, "Meditsina," 1974.

2. Il'yuchenok, R. Yu., Leutin, V. P., Vol'f, N. V. and Tsvetovskiy, S. B., ZH. VYSSH. NERVN. DEYAT., Vol 25, No 5, 1975, p 981.

3. Il'yuchenok, R. Yu., "Neurochemical Mechanisms of the Brain and Memory," Novosibirsk, "Nauka," 1977.

4. Korsakov, I. A., Gilinskiy, N. A. and Il'yuchenok, R. Yu., ZH. VYSSH. NERVN. DEYAT., Vol 25, No 6, 1975, p 1300.

5. Kruglikov, R. I., Ibid, Vol 21, No 2, 1971, p 419.

6. Idem, USPEKHI FIZIOL. NAUK, Vol 9, No 3, 1978, p 3.

7. Smirnov, V. M. and Borodkin, YU. S., FIZ. CHEL., Vol 1, No 3, 1975, p 525.

8. Khromov-Borisov, N. V., Borisova, G. Yu., Aleksandrova, I. Ya., Gol'dfarb, V. L., Brovtsyna, I. B., Zaytsev, Yu. V. and Borodkin, Yu. S., ZH. VYSSH. NERVN. DEYAT., Vol 28, No 4, 1978, p 761.

9. Bures, J. and Buresova, O., J. COMPAR. AND PHYSIOL. PSYCHOL., Vol 56, 1963, p 268.

10. Dall'Olio, R., Gandolfi, O. and Montanaro, N., PHARMACOL. RES. COMMUN., Vol 10, No 9, 1978, p 851.

11. Davis, H. P., Rosenzweig, M. R., Bennet, E. L. and Orme, A. E., PHARMACOL. BIOCHEM. BEHAV., Vol 8, 1978, p 701.

12. Deutsch, J. A., SCIENCE, Vol 174, No 4011, 1971, p 788.

13. Frinder, B. and Allweis, C., BEHAV. BIOL., Vol 22, No 2, 1978, p 179.

14. Frontali, M., Amorico, L., DeAcetis, L. and Bignami, G., Ibid, Vol 18, No 5218, 1976, p 1.

15. Gold, R. E., Haycock, J. W., Macri, J. and McGaugh, J. L., SCIENCE, Vol 180, No 4091, 1973, p 1199.

16. Levis, D. J., PSYCHOL. REV., Vol 76, No 5, 1969, p 461.

17. Levis, D. J. and Bregman, N. J., PSYCHOL. BEHAV., Vol 8, No 3, 1972, p 511.

18. Levis, D. J., Misanin, J. R. and Miller, R. R., NATURE, Vol 220, No 5168, 1968, p 704.

19. McGaugh, J. L., SCIENCE, Vol 153, No 3743, 1966, p 1351.

20. Miller, A. J., J. COMPAR. PHYSIOL. PSYCHOL., Vol 66, 1968, p 40.

21. Misanin, J. R., Miller, R. R. and Levis, D. J., SCIENCE, Vol 160, No 3827. 1968, p 554.

22. Quartermain, D., McEwen, B. S. and Azmitia, E. C., Ibid, Vol 169, No 3946, 1970, p 683.

23. Springer, A. O. and Miller, R. R., Ibid, Vol 177, No 4049, 1972, p 628.

24. Ungar, G., in "Memory and Transfer of Information," New York--London, 1973, p 317.

25. Zinkin, S. and Miller, A. J., SCIENCE, Vol 155, No 3758, 1967, p 102.

10,657
CSO: 1840/206

UDC: 591.26:612.821:(615+615.9)

GROUP RELATIONS AMONG ANIMALS: SOME ASPECTS OF POPULATION PHYSIOLOGY IN PHARMACOLOGY AND TOXICOLOGY

Leningrad GRUPPOVYYE OTNOSHENIYA ZHIVOTNYKH: NEKOTORYYE ASPEKTY POPULYATSIONNOY FIZIOLOGII V FARMAKOLOGII I TOKSIKOLOGII in Russian 1980 (signed to press 24 Jul 80) pp 2-4, 145

[Annotation, introduction and table of contents from book "Group Relations Among Animals (Some Aspects of Population Physiology in Pharmacology and Toxicology)", by Eleonora Raymondovna Uzhdavini, Scientific Council for Complex Problems of Human and Animal Physiology and Institute of Evolutionary Physiology and Biochemistry imeni I. M. Sechenov, USSR Academy of Sciences, Izdatel'stvo "Nauka", 1250 copies, 145 pages]

[Text] This book deals with problems of population physiology and pharmacology. It discusses processes of formation of the group structure and effects of group factors on animal resistance to chemicals. Data are also submitted on the functional state of animals and changes in their reactivity apart from zoosocial influences. There is discussion of general questions of individual sensitivity and some practical problems of modeling in experimental biomedical research. Use of pharmacological tests to investigate some problems of supraorganismic regulation in population of physiology is interesting in the general biological aspect. The issues discussed in this book may be of some interest to agriculture, in particular, livestock breeding, when using group methods of cattle upkeep and implementing various zootechnical measures on groups of animals. References 603, illustrations 10, tables 32.

Introduction

Individual sensitivity to drugs and industrial chemicals is an important and little-developed branch of experimental biology and medicine. Aside from its general biological and theoretical significance, this problem has a direct bearing on experimental modeling in pharmacology and toxicology, as well as scientific validation of extrapolation of data obtained from experiments with animals both to clinical practice and industrial and communal hygiene.

When examining the species-specific sensitivity of man and animals to various chemicals, the researcher encounters, first of all, its genetic determination. Evidently, genetic factors also play a large part in the outcome of the effects of drugs, industrial toxic agents on specimens of the same species. But, in addition, biorhythms, changes in physiological state, under the influence of internal, particularly humoral, factors as well as exogenous living conditions, are capable, of course over a narrower range, of altering reactivity to "chemical factors."

In recent years, the supraorganismic level of organization of life is drawing increasing attention, as one of the pressing problems of modern biology and medicine (populations and biocenoses, intragroup interactions and their effects on various aspects of vital function, dynamics of population size, etc.). The relations that develop in a community or group of animals affect morphological signs and functional state of individual specimens.

The research of Chance (1946), who discovered the phenomenon known under the name of "group toxicity of phenamine," as well as the field and laboratory observations of Christian (1950, 1955), who established the influence of population density on the endocrine system of mammals, originated comprehensive investigation of these questions. Isolation is the most popular method of studying the role of zoosocial influences in experimental pharmacological and toxicological research. For a number of years, while we worked in the laboratory on toxicity of chemicals as a function of group factors, we could not leave unheeded the changes observed in animals when they are isolated from a community. The rather vast material accumulated on this question by different researchers has not been analyzed in the literature. Yet, it is not only interesting but necessary to sum up the facts as they pertain to the problem in question. The same applies to the process of formation of a group structure, morphological and physiological characteristics of different specimens in a group. For this reason, considerable space is devoted in this book to a description of morphological and functional changes in animals which are isolated and with formation of a group hierarchy.

As yet, there are few experimental data concerning the role of group factors in animal reactivity and sensitivity to chemicals, and now this area is at the stage of accumulation of factual material. Nevertheless, we believe it necessary to discuss the status of this question at the very earliest stage of its development. Consideration of available data, as well as determination of priority tasks, would facilitate the matter of more purposeful collection of material.

The book offered to the reader's attention deals with problems of population physiology and pharmacology. It discusses the process of formation of group structure and its influence on resistance to chemicals; there are data on the functional state of animals and changes in reactivity aside from zoosocial influences. There is discussion of general questions of individual sensitivity and some practical problems related to modeling in experimental biomedical research.

Contents

10,657
CSO: 1840/197

PSYCHOLOGY

UDC: 155.552+154.2

INVARIANT METHOD OF IDENTIFYING THE EMOTIONAL STATE OF A GROUP OF SPEAKERS ON THE BASIS OF THEIR SPEECH

Moscow ZHURNAL VYSSHEY NERVNOY DEYATEL'NOSTI IMENI I. P. PAVLOVA in Russian Vol 26, No 1, Jan-Feb 76 pp 196-199

[Article by P. V. Simonov, M. V. Frolov and V. L. Taubkin, Institute of Higher Nervous Activity and Neurophysiology, USSR Academy of Sciences, Moscow, submitted 7 Apr 75]

[Text] In our previous publications, we described some spectral and spectral-time methods of evaluating the emotional state of a specific announcer [speaker] from a given fragment of speech [1, 3, 4]. The flaws of these methods include the difficulty of analysis on a real time scale and substantial integrative nature of spectral ratings. The latter circumstance made it easier to single out a signal against the background of noise, which was part of the purpose of the study, but at the same time led to loss of information. This diminished the effectiveness of the methods, particularly in the case of minimal emotional tension, which was evaluated according to changes in heart rate.

We submit here the first results of our search and use of a set of parameters to solve the general problem of assessing the emotional state of any speaker on the basis of any fragment of speech.

The studies can be divided into three stages: 1) modeling emotions and gathering the necessary verbal material; 2) development of the method; 3) practical verification and correction of obtained results under natural conditions. In our experiments, we used the procedure of modeling emotional states by means of role playing [1, 2]. The method consisted in essence of asking an actor to imagine the situation in which a man develops a given emotion (specified [proposed] circumstances in the terminology of K. S. Stanislavskiy) rather than to express a given emotion (anxiety, joy, etc.). We expected that the emotional experiences of the speaker would be reflected in his speech. We were able to differentiate between genuine emotional reactions and purely imitative reproduction of the emotional coloration of speech of an absolutely calm actor by recording the electrocardiogram during recording of speech on tape. Substantial changes in heart rate (up to 30-35 beats per minute, as compared to a calm state) and the results of listeners' evaluation of speech enabled us to consider the speakers's emotional reactions to be close to natural emotions in the vast majority of cases of deliberate portrayal of joyous excitement (Р), delight [ecstasy] (В), alarm [anxiety] (Т) and fear (С). We recorded speech at a normal volume in cases of speaking calmly (П), dictating (Д), talking rapidly (С) and louder speech under analogous

conditions with respect to pronunciation (Пг, Дг, Сг).* A total of 57 actors and graduating class drama students participated in the experiments. Three 1-h experiments were conducted with each of them, which enabled us to gather the verbal material necessary for mathematical processing.

In view of the difficulty of the proposed task and previously obtained results [3, 4], we decided to limit ourselves at this stage of investigation to analysis of vowel sounds. As we know, two factors play a substantial part in forming them: the vocal source and resonance system of the nasopharynx [4]. This is why we selected as informative parameters the frequency of the fundamental tone [F_{om} in Figures 1 and 3 and equations] and mean number of intersections of zero level in the frequency band of the first formant, which enabled us to assess the state of the source and acoustic resonators. The fundamental tone frequency F_{om} was isolated by a method similar to peak detection of a signal with subsequent conversion of the result into a smoothed oscillatory function carrying information about the intonational structure of speech. The mean number of intersections (frequency of zeros--f_0) was measured after clipping the process and, in our case, it described the position of the first formant on the frequency axis. Thus, the system of parameters selected at this stage of our investigations reflected the already known data from spectral analysis of speech (deformation of formant structure) and our conceptions of other carriers (fundamental tone parameters) of emotionally meaningful information in the verbal signal.

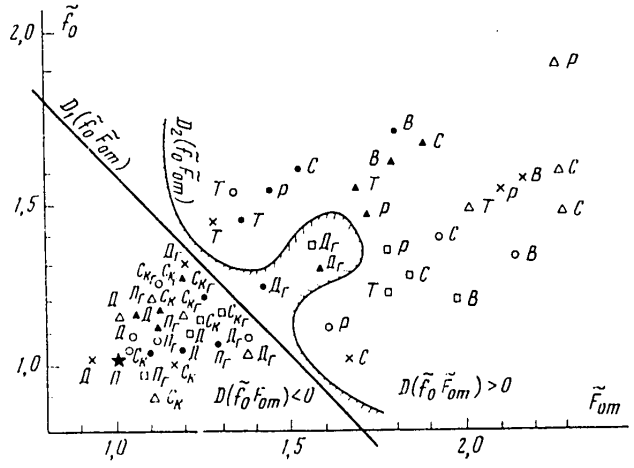


Figure 1. Explanation given in text

Figure 1 illustrates an example of identification of states of calmness (with consideration of temporal and volume variations) and different levels and signs of emotional tension in six arbitrarily chosen speakers. In this figure, the position of the "O" sound in the word "ponyal" [understood] is shown in the plane of dimensionless parameters:

*Translator's note: Russian letters were retained to conform with symbols used in Figures 1 and 3. The "C" was indeed used for the indicated two designations.

$$\tilde{F}_{om} = \frac{F_{om}}{F_{om\pi}} \quad \tilde{f}_0 = \frac{f_0}{f_{o\pi}}$$

where $f_{o\pi}$ and $F_{om\pi}$ are the values of the corresponding parameters in a calm state. Each point of the analyzed sets, designated with squares, triangles, etc., was obtained by averaging three expressed sounds. Maximum scatter in relation to the mean value did not exceed 10%. The studies revealed that use of a linear solving function of the following appearance:

$$D_1(\tilde{F}_{om}, \tilde{f}_0) = A\tilde{F}_{om} + B\tilde{f}_0 + C \qquad (1)$$

where A, B, C are certain constants, enabled us to correctly identify emotional states,

$$D(\tilde{F}_{om}, \tilde{f}_0) > 0$$

and calm states,

$$D(\tilde{F}_{om}, \tilde{f}_0) < 0$$

in 92-94% of all considered cases, including changes in style of pronunciation. These are better results than those obtained by the spectral method [5]. For this group of speakers, coefficients A, B and C in the training process were used with the following values: A = 1.09, B = 1 and C = 1.8. It was also learned that use of a solving function such as (1) leads to appreciable identification errors in situations of the "loud dictation" type. This flaw can be eliminated by selecting a more complicated solving function (Figure 1) such as $D_2(\tilde{F}_{om}, \tilde{f}_0)$ or by addition of new speech parameters. In the latter case, as shown by preliminary analysis, one can use the volume of the verbal signal and certain temporal characteristics: word uttering time, pauses, etc. Figure 2 illustrates changes in mean interval of cardiac contractions T_{R-R}, which were obtained with modeling of states S in the group of six speakers under study. Analysis of these curves, the designations of which are analogous to those used in Figure 1, is indicative of presence of substantial changes in the heart rate of our speakers.

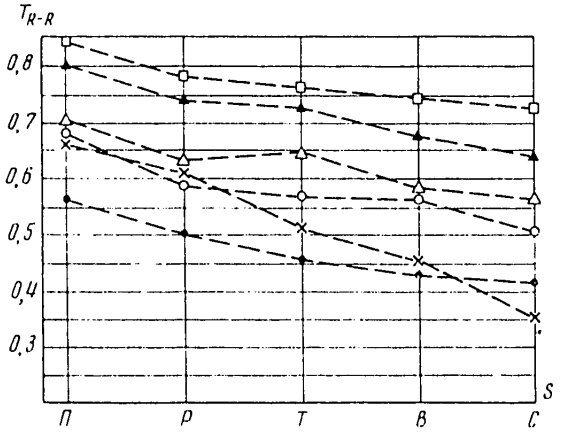


Figure 2. Explanation given in text

The described method was used to identify calm states and states of emotional tension in athlete parachute jumpers during jumps. Speech was recorded by means of throat microphones, which ruled out the influence of noise due to air flow, and a special telemetry system. We recorded the pulse rate concurrently with speech. In our processing, we used runs of verbal signals selected on the basis of pulsometric data and listeners' analysis, as well as analogous speech fragments uttered by the same speakers at rest on the ground. Figure 3 illustrates identification of the states in the plane of dimensionless parameters $\tilde{f}_0$ and $\tilde{F}_{0m}$ for three parachutist speakers. This figure shows the dynamics of positions of vowel sounds which were cut out in the order of their appearance in phrases of the "Ya (familiya), vas ponyal" [I (surname) understand you] type. Each point of the curves was obtained from averaging three runs. Analysis of the data illustrated in Figure 3 was indicative of reliable identification. None of the runs of the vowel sounds exceeded the zone defined in the course of actors' portrayals as the range of emotional states.

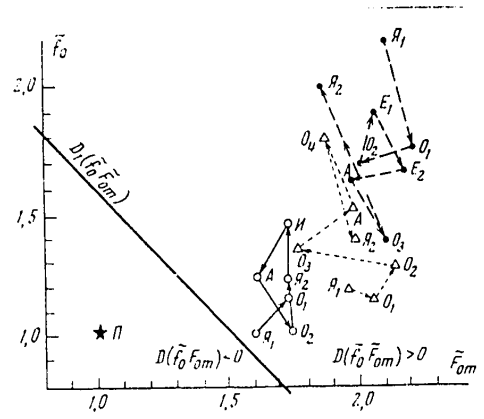


Figure 3.
Explanation given in text

The proposed method is based on a physiological model of the vocal [verbal] tract and spectral rating of emotional states obtained previously. In our opinion, this is what determined the rather high percentage of correct identification of fragments of emotionally colored speech in the group of speakers. It should be stressed that, in the case in question, evaluation of the state of any of the speakers in the group was made on the basis of different runs of vowel sounds, which is an important step toward solving the general problem of identifying emotions from a verbal signal. Unquestionably, the set of informative parameters found at this stage of analysis and structure of the identifying device require further refinement and broader verification in practice. Nevertheless, the submitted results are indicative of the validity of using the actor model in research experiments, and they can serve both practical purposes and as the basis for future studies.

BIBLIOGRAPHY

1. Popov, V. A., Simonov, P. V., Frolov, M. V. and Khachatur'yants, L. S., ZH. VYSSH. NERVN. DEYAT., Vol 21, No 1, 1971, p 104.
2. Simonov, P. V., "The Method of K. S. Stanislavskiy and Physiology of Emotions," Moscow, Izd-vo AN SSSR [USSR Academy of Sciences], 1962.
3. Frolov, M. V., in "Fiziologicheskiye osobennosti polozhitel'nykh i otritsatel'nykh emotsional'nykh sostoyaniy" [Physiological Distinctions of Positive and Negative Emotional States], Moscow, "Nauka," 1972, p 128.

4. Simonov, P. V. and Frolov, M. V., AEROSPACE MEDICINE, Vol 44, No 3, 1973, p 256.

5. Luk'yanov, A. N. and Frolov, M. V., "Signals of Human Operator State," NASA, Washington, D.C., 1970.

10,657
CSO: 8144/0969

- END -